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TECHNICAL NOTE

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NACA AND OFFICE OF NAVAL RESEARCH METALLURGICAL INVESTIGATION OF TWO LARGE FORGED DISCS OF S-590 ALLOY

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Washington
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SUMMARY

The properties of large forged discs of S-590 alloy at room temperature, 1200°, 1350°, and 1500° F were studied in order to determine the level of properties obtainable in forgings of the type required for the rotor discs of gas turbines. One disc was aged after forging. The other was solution-treated and aged. A limited amount of testing was carried out on the solution-treated disc prior to aging. The data reported include the results of tensile, impact, rupture, time-deformation, creep, and structural-stability tests.

The high physical properties of the forged and aged disc at temperatures up to 1350° F were its outstanding characteristic. The solution-treated and aged disc had by far the best properties at 1500° F and, except at short time periods, was considerably better at 1350° F. Somewhat higher rupture, total-deformation, and creep strengths for time periods up to at least 2000 hours were obtained at 1200° F from the forged and aged disc. No great difference, on the basis of limited tests at 1200° and 1350° F, resulted from testing the solution-treated disc before aging.

The properties of specimens cut from different locations in the discs varied somewhat. However, the uniformity was good for the type of forging made from such a highly alloyed material.

Both the forged and aged and solution-treated and aged materials were structurally unstable during creep and rupture testing. The latter treatment, however, resulted in the best retention of properties over long periods of time at high temperatures.

The properties of the solution-treated and aged disc were similar to those reported for bar stock with the same heat treatments. This indicates that the properties should be reasonably reproducible in discs up to the size considered in this investigation. Reproduction of the properties of the as-forged and aged disc would probably require a considerable degree of control of forging practice.

The work on which this report is based is part of a cooperative investigation of several heat-resistant alloys in the form of large forged discs. The properties of the S-590 discs are compared in this report with those obtained for similar discs of S-816 alloy.

INTRODUCTION

This report presents the results of a study of the room-temperature, 1200°, 1350°, and 1500° F properties of two large discs of S-590 alloy. One of the discs was tested in the as-forged and aged condition. The other disc was tested to a limited extent after only a solution treatment; and more completely tested as solution-treated and aged.

The primary purpose of this study was to determine the level of properties exhibited by S-590 alloy in the form of large forgings of the type required for rotor discs of gas turbines and to determine the relative properties of such discs as-forged and aged and as-solution-treated and aged. The S-590 alloy discs, for which properties are given in this report, were two of a series of similar discs of several alloys now being studied. The results obtained previously from similar investigations on 19-9DL, CSA, low-carbon N-155, Timken, and EME discs are contained in references 1 to 9.

The work on the disc materials is being carried out as part of two correlated programs of research on alloys for gas-turbine applications in progress in this country. The National Advisory Committee for Aeronautics is sponsoring work directed toward the development of improved high-temperature alloys for gas turbines used in aircraft power plants. A concurrent program, formerly sponsored by the National Defense Research Committee, Office of Scientific Research and Development, and now sponsored by the Office of Naval Research, Navy Department, is being directed to the development of alloys for gas-turbine applications in general and, in particular, to both ship and aircraft propulsion. The work herein was performed with the financial assistance of the National Advisory Committee for Aeronautics and the Office of Naval Research, Navy Department.

This report is based on the joint effort of the cooperating research programs and is being distributed by both the NACA and the Navy. The investigation of these discs for the NACA was conducted at the Engineering Research Institute of the University of Michigan and for the Navy by Battelle Memorial Institute.

TEST MATERIALS

The code number assigned to the discs was NR-74B. The as-forged and aged disc was designated NR-74B-F; the solution-treated disc, NR-74B-Q; and the aged portion of the solution-treated disc, NR-74B-QA.

The available information describing the two discs may be summarized as follows:

Manufacturer:

Allegheny-Ludlum Steel Corporation

Heat number:

41582

Chemical composition:

C	Mn	Si	P	S	Cr	Ni	Co	Mo	W	Cb	Fe
0.45	1.44	0.56	0.015	0.018	19.76	19.05	20.20	4.03	4.08	3.35	Remainder

Fabrication procedure:

A 12-inch ingot was poured from a 2-ton electric-arc furnace. The 12-inch ingot was hammer cogged from 2250° F to a 9-inch-square billet which was air-cooled and ground. Two portions of this billet were then upset forged from 2250° F to rough 4-inch-thick discs. All hot-working was with a flat die on a 12,000-pound hammer. The finishing and heat treatments for the individual discs were as follows:

Disc designation	Finish forging procedure	Heat treatment
NR-74B-F	The disc was reforged from 2250° F to $3\frac{3}{4}$ inches thick and cooled. Then it was reforged from 2000° F in one heat to $3\frac{3}{8}$ inches thick (10-percent reduction) by 18 inches in diameter.	Aged for 16 hours at 1400° F and air-cooled.
NR-74B-Q	The disc was reforged from 2250° F to 3 inches thick by 18 inches in diameter.	Solution-treated for $3\frac{1}{4}$ hours at 2300° F and water-quenched.
NR-74B-QA	Same forging as NR-74B-Q. Coupons of disc NR-74B-Q which were aged prior to testing were designated NR-74B-QA.	Coupons from NR-74B-Q were aged for 16 hours at 1400° F and air-cooled.

Sampling:

One-half of each of the two discs, NR-74B-F and NR-74B-Q, was supplied for the present study, one-quarter of each disc going to the University of Michigan and Battelle Memorial Institute, respectively. Figures 1 and 2 show the location of the samples cut from the halves of both discs and the code system identifying the coupons. The numerals refer to locations on the flat faces of the discs, and the letters refer to the locations through the thickness of the discs.

EXPERIMENTAL PROCEDURE

The investigation was designed to provide the following information: (1) The physical properties at room temperature, 1200°, 1350°, and 1500° F which can be expected in large forgings of the S-590 alloy analysis; (2) the effect of fabrication and heat treatment on these physical properties; (3) the variation in properties which might be present in various locations in such large forgings; and (4) the change in room-temperature properties resulting from exposure to elevated temperatures under stress for prolonged time periods.

The physical-property data obtained for these large forged discs of S-590 alloy included short-time tensile properties, impact strengths, rupture test characteristics, design curves of stress against time for total deformations of 0.1, 0.2, 0.5, and 1.0 percent at 1200°, 1350°, and 1500° F, and creep characteristics. The curves of stress against time for total deformation were obtained from curves of elongation against time from both stress-rupture and creep tests.

The uniformity of the disc materials was checked by means of a hardness survey and to a limited extent by tensile and rupture tests on coupons from representative locations throughout the discs. Hardness, tensile, and impact tests and metallographic examinations on specimens after completion of the tests were used to estimate the stability of the material during prolonged exposure to temperature and stress.

The testing procedures used for the short-time tension, stress-rupture, and creep tests were in accordance with the provisions of the A.S.T.M. Recommended Practices E21-43 and E22-41.

RESULTS

The data obtained from the S-590 discs are presented as a series of tables and figures which show the hardness, impact, tensile, rupture, time-deformation, creep, and stability characteristics. The principal results on the discs with three types of treatment are summarized in figures 3 and 4.

Hardness Survey

Results of hardness tests on the original materials are given in table I and figure 5. The surveys indicated that the hardness increase was only slight from the center to the rim of the discs. The material at the flat surfaces of the discs was considerably harder than the material in the interior of the discs.

The as-forged and aged disc, NR-74B-F, had a hardness range of 235 to 311 as compared with a range of 190 to 235 Brinell hardness for the solution-treated disc, NR-74B-Q. Although no hardness survey was made on the solution-treated and aged disc material, NR-74B-QA, hardness tests indicated that aging the solution-treated material increased the hardness by approximately 30 Brinell points.

Short-Time Tensile Properties

The results of the short-time tensile tests at room temperature, 1200°, 1350°, and 1500° F are summarized in table I.

The tensile strengths of the as-forged and aged disc, NR-74B-F, were in general somewhat higher, while its yield strengths were markedly higher at both room temperature and 1200° F than those of the heat-treated disc. At 1350° F the forged and aged disc had similar tensile strength but higher yield strength than the solution-treated and aged disc. On the basis of only one test the as-solution-treated material had higher tensile strength but similar yield strength to the material aged after solution treatment. At 1500° F the solution-treated and aged material, NR-74B-QA, was slightly stronger than the as-forged and aged material. A brief résumé of comparative tensile properties taken from table I is given in the following tabulation:

Disc	Temperature (°F)	Tensile strength (psi)	0.2-percent-offset yield strength (psi)	Elongation (percent)
NR-74B-F	75	129,050	98,250	8
NR-74B-Q	75	119,500	57,000	36
NR-74B-QA	75	130,500	70,500	17
NR-74B-F	1200	88,700	71,750	15
NR-74B-Q	1200	82,000	44,000	12
NR-74B-QA	1200	81,600	49,000	27
NR-74B-F	1350	64,625	55,000	29
NR-74B-Q	1350	71,250	46,000	11
NR-74B-QA	1350	65,750	46,000	25
NR-74B-F	1500	43,125	35,900	25
NR-74B-QA	1500	44,400	37,850	18

At room temperature the solution-treated disc, NR-74B-Q, had the highest ductility and the as-forged and aged disc, NR-74B-F, the lowest ductility. The reverse ductility comparison was true at high temperature. Aging the solution-treated disc for 16 hours at 1400° F caused a substantial decrease in room-temperature tensile ductility but resulted in just as marked an improvement in ductility at temperatures of 1200° F and above.

The properties of specimens from various locations in the discs were quite uniform. Specimens taken tangentially from the as-forged and aged disc had higher strengths than the radial specimens. No such strength difference was observed between radial and tangential specimens of the solution-treated disc. Because of lack of material no consistent comparison was possible for material taken radially near the surface and center material. However, what data there were indicated good uniformity.

Charpy Impact Resistance

Charpy impact resistance (V-notch) was determined on specimens from two discs, NR-74B-F and NR-74B-QA. Data are shown in table II and figures 3 and 4 for tests at room temperature, 1200°, 1350°, and 1500° F after holding at temperature for a time period sufficiently long to insure a uniform temperature in the specimen.

The Charpy impact resistance of the solution-treated and aged disc was slightly higher at all test temperatures than that of the forged and aged disc. For both discs, there was a slight increase in impact resistance with temperature. Specimens from near the flat surfaces of both discs had higher impact resistance than interior specimens at all temperatures.

Rupture Test Characteristics

The stress-rupture data for the tests at 1200°, 1350°, and 1500° F are shown in table III, and the rupture strengths obtained from the curves of stress against rupture time in figure 6 are summarized in table IV. Rupture ductilities at various time periods are also given in table IV. All specimens tested except one were radial specimens, located as indicated in table III.

There was very little difference in rupture strengths between the three conditions of treatment for the discs at 1200° F. The solution-treated and aged disc, NR-74B-QA, did show a slight superiority at time periods of 1000 hours and longer, its 100- and 1000-hour rupture strengths being 52,000 and 42,000 psi, respectively.

At 1350° F the solution-treated discs were definitely superior to the forged and aged disc at 100 hours and longer. Comparative rupture strengths were 32,000 psi for NR-74B-QA and 27,500 psi for NR-74B-F at 100 hours and 25,000 psi for NR-74B-QA compared with 18,000 psi for NR-74B-F at 1000 hours. Aging the solution-treated disc for 16 hours at 1400° F did not affect rupture strengths at 1350° F.

The solution-treated and aged disc was much stronger than the forged and aged disc at 1500° F. The comparative 100-hour rupture strengths for the two discs were 20,000 and 13,100 psi and 1000-hour strengths were 15,000 and 6,000 psi.

Inspection of the curves of stress against rupture time in figure 6 indicates little change in the slope of the curves with increased temperature of testing for the solution-treated disc. The increased slope of the curves for the forged and aged disc with increasing temperature accounts for its lower strength. This difference clearly indicates the beneficial effect of a solution treatment on properties at temperatures above 1200° F.

The rupture tests on specimens from various locations in the discs indicated that the disc material was fairly uniform and that, if anything, the material taken radially near the rim in the center plane tended to be weaker than material from other locations. Thus, since most of the material tested came from this location, the results obtained were probably conservative for the properties of the disc as a whole.

Rupture test ductilities shown were better for the solution-treated and aged disc than for the forged and aged disc in all cases. Aging the solution-treated material produced a marked improvement in rupture ductility at 1200° F but had little effect on ductility at 1350° F. Actually, the ductility of all the material was good, being at least 5 percent for fracture in 1000 hours.

Time-Deformation Characteristics

A convenient method of describing the high-temperature strength of a material is curves of stress against the time required for various total deformations. Deformation data from both stress-rupture and creep tests are used to prepare such design curves. This information, along with the curves of stress against rupture time, gives a fairly complete picture of the expected performance of an alloy under conditions of constant tensile stress. The time-deformation data obtained on the S-590 discs in three conditions are plotted on semilogarithmic coordinates in figures 7 to 14 for total deformations of 0.1, 0.2, 0.5, and 1.0 percent at 1200°, 1350°, and 1500° F for time periods up to 2000 hours. Additional curves which indicate the time of transition from a minimum creep rate to the increasing rate of third-stage creep have been added so as to show where rapid elongation preceding failure starts.

The curves of stress against time for total deformation were plotted from the data in tables V, VI, and VII. These data were taken from the curves of elongation against time for the rupture and creep tests. Somewhat erratic data resulted from the tests. Sufficient check tests were made, however, to demonstrate that these erratic results were due to a variation between specimens from different locations in the discs. The actual curves of elongation against time have not been included in this report.

The stresses to cause various total deformation in 1, 10, 100, 1000, and 2000 hours, as defined by the curves in figures 7 to 14, are given in tables VIII, IX, and X. The most pronounced difference between discs was found at 1500° F where the solution-treated and aged disc had deformation strengths from two to three times higher than those of the forged and aged disc. The difference between the discs was much less at 1200° and 1350° F. The forged and aged disc gave strengths somewhat higher than the solution-treated disc and both were higher than the solution-treated and aged material at 1200° F, particularly at 0.5-percent total deformation. At 1350° F the solution-treated and aged material had higher strengths, the degree of superiority increasing with the amount of total deformation considered.

Creep Strengths

Many engineers are accustomed to base designs on creep rates, especially for long periods of service. For this reason, the creep rate data have been collected from the curves of elongation against time and are shown in table XI for creep tests and table III for rupture tests. The logarithmic curves of stress against creep rate for the tests at 1200°, 1350°, and 1500° F on the S-590 discs are shown in figure 15.

The creep rates plotted were either minimum rates or final rates from 1000-hour tests at 1200° F and 2000-hour tests at 1350° and 1500° F. The creep strengths obtained from figure 15 were as follows:

Disc	Temperature (°F)	Stress (psi) for creep rates of –	
		0.0001 percent/hr	0.00001 percent/hr
NR-74B-F	1200	27,500	------
NR-74B-QA	1200	23,000	------
NR-74B-F	1350	10,600	------
NR-74B-QA	1350	16,400	12,100
NR-74B-F	1500	[a]2,800	------
NR-74B-QA	1500	10,000	7,100

[a]Estimated strength.

It is observed that at temperatures above 1200° F the solution-treated and aged disc, NR-74B-QA, is much superior to the forged and aged disc, NR-74B-F.

These creep strengths can be compared with the deformation strengths in tables VIII, IX, and X. The creep strengths for a rate of 0.0001 percent per hour at 1200° F are apparently safe for use for time periods up to 10,000 hours since extrapolation of the curves of transition to third-stage creep in figures 7 and 9 to 10,000 hours indicates that at the creep strengths listed second-stage creep will still prevail.

At 1350° and 1500° F extrapolation of the transition curves of figures 12 and 14 to 10,000 hours gives stresses about the same as those producing a creep rate of 0.0001 percent per hour for the solution-treated and aged disc, NR-74B-QA. This is not true for the forged and aged disc, NR-74B-F, transition to third-stage creep occurring in approximately 2000 hours under stresses causing a creep rate of 0.0001 percent per hour. (See figs. 10 and 13.) This means that the reported creep strength for NR-74B-F at these higher temperatures would not be suitable as a basis for design for longer time periods than 2000 hours, while the creep strengths of NR-74B-QA can be used, with caution, out to 10,000 hours.

At 1200° F the data were not sufficient to define the strengths for a creep rate of 0.00001 percent per hour. At higher temperatures the slopes of the curves of stress against rupture time indicate that creep strengths for this rate would not be suitable as a basis for design for prolonged time periods for the forged and aged disc and that caution should be observed when extended service periods are contemplated for solution-treated and aged material.

Stability Characteristics

Some of the completed-test specimens from each of the discs were subjected to tensile, impact, and hardness tests at room temperature, after creep testing at 1200°, 1350°, and 1500° F, with the results shown in table XII.

The most significant property changes observed as a result of creep testing were the decreases in impact resistance and tensile test ductility at room temperature. Impact strengths were low initially and were very low after creep testing. The decrease in ductility was even more pronounced than that of impact strength.

There was no significant change in hardness as a result of creep testing for the forged and aged disc, but the solution-treated and aged disc increased in hardness during testing. The tensile-test strength properties of the forged and aged disc, NR-74B-F, decreased progressively with increasing creep test temperature. Those of the as-solution-treated material, NR-74B-Q, increased as a result of a 1200° F creep test, while the strengths of the solution-treated and aged disc, NR-74B-QA, were higher after creep tests at 1200° and 1350° F, but were lower in strength than the original material after a 1500° F creep test.

Photomicrographs of the structures of the original materials and after creep and rupture testing are shown in figures 16 to 22. The forged and aged disc, NR-74B-F, had nonuniform structure as evidenced by grain-size differences and distribution of the excess constituents. (See fig. 16.) These differences were also observed in the structure of some of the completed-test specimens.

Only a small amount of general precipitation was observed in the forged and aged disc as a result of creep and rupture testing at 1200° F. (See figs. 17(a) and 18(a).) Considerable agglomeration occurred during testing at 1350° F. The differences in amount of precipitate between the creep and rupture test specimens, shown by comparison of figures 17(b) and 18(b), were another indication of nonuniformity of material. Further agglomeration of the precipitated phases was observed in the 1500° F rupture specimen. (See fig. 18(c).)

The original microstructures of the solution-treated disc, NR-74B-Q, and the solution-treated and aged disc, NR-74B-QA, (fig. 19) were different in that more precipitates were present in the aged material. Heavy general precipitation occurred during rupture and creep testing of both materials and agglomeration increased as the test temperature was increased. The precipitation did not appear quite so heavy in the creep specimens as in the rupture specimens.

Fracture of the longest-time rupture specimens of the forged and aged disc appear to be both transgranular and intergranular while those of the solution-treated discs were largely intergranular.

Allegheny-Ludlum Data on NR-74B Discs

Table XIII gives the available results from tensile, hardness, and rupture tests obtained by the Allegheny-Ludlum Steel Corporation on the other halves of these S-590 discs. Also listed are comparative results obtained in this investigation. In general, the comparative results show good agreement.

CONCLUDING REMARKS

In general, the solution-treated and aged disc had the best properties at high temperatures. At 1200° F the forged and aged disc had better rupture strengths out to 100 hours and higher total-deformation strengths to at least 2000 hours. At 1350° and 1500° F the solution-treated and aged disc was definitely superior in properties. On the basis of a limited number of tests at 1200° and 1350° F, the properties of a plain solution-treated disc were almost the same as those for the solution-treated and aged disc material.

The as-forged and aged disc had much higher yield strength at room temperature, 1200°, and 1350° F than the solution-treated and aged disc. This characteristic might be important in applications involving high stresses at low temperatures at the centers of rotor discs or in applications involving high stresses for short time periods up to 1350° F.

The data reported by the Allegheny-Ludlum Steel Corporation show that aging the as-forged disc at 1400° F reduced properties at room temperature and probably increased rupture strength at 1350° F. Increasing the aging temperature to 1500° F further reduced yield strength at room temperature and lowered rupture strength below that of the material aged at 1400° F. Their data also show that aging at 1500° F after a solution treatment results in somewhat lower rupture strength at 1500° F than aging at 1400° F, at least for time periods longer than about 100 hours.

Table XIV has been prepared to show the comparative properties of solution-treated and aged bar stock of S-590 alloy and large discs. The tensile properties of bar stock were somewhat higher than a similarly treated disc. Rupture properties at 1350° and 1500° F and total-deformation properties at 1500° F agree quite well for the solution-treated and aged bar stock and the disc, an indication of the possibility of good reproducibility of high-temperature properties in different forms for S-590 alloy.

The properties of the discs had, in general, good uniformity for such large forgings of highly alloyed material. Wide variations in grain size and microstructure did not appear to affect properties greatly, except to cause erratic data for the studies of stress against time for total deformation. Such variations as were present were reduced somewhat by the solution and aging treatment.

A major problem in using data of the type obtained in this investigation is to estimate the degree of reproducibility. Experience with other high-alloy steels indicates that fairly good control over forging practice would be required to reproduce consistently the properties of the as-forged and aged disc. The agreement in properties between bar stock and the disc when solution-treated and aged suggests that the properties of discs should be fairly reproducible when heat-treated. Until more data on the properties of discs made by this and, especially, other fabrication procedures are available, it should be assumed that the data herein reported apply only to the particular discs tested and fabricated and heat-treated in the manner indicated.

The heat treatments used on the discs covered by this investigation were based on a large amount of experimental work by the Allegheny-Ludlum Steel Corporation. Deviation from these conditions would result in pronounced changes in properties at high temperatures.

Table XV presents a summary of the comparative properties of discs of two alloys, S-590 and S-816 (see reference 10), studied at 1200°, 1350°, and 1500° F in the cooperative research program. This comparison shows, in general, that for similarly treated material the S-816 alloy disc has better properties than the S-590 alloy disc.

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TABLE I

SHORT-TIME TENSILE PROPERTIES OF S-590 ALLOY DISCS NR-74B

[NACA data except where indicated. All tensile tests were made on standard 0.505-in.-diameter specimens]

Disc (a)	Specimen number	Specimen location (b)	Temperature (°F)	Tensile strength (psi)	Offset yield strengths (psi)			Proportional limit (psi)	Elongation in 2 in. (percent)	Reduction of area (percent)	Brinell hardness	Modulus of elasticity
					0.02 percent	0.1 percent	0.2 percent					
NR-74B-F	14Y	CRR	75	130,600	69,000	91,000	100,000	37,500	9	11.5	267	30.5×10^6
	14X	SRR	75	127,500	72,500	89,000	96,500	47,500	7	9.2	267-302	29.9
	16Y	CTR	75	137,750	75,000	99,000	108,000	37,500	11.5	23.2	293	28.8
	16X	STR	75	147,000	91,000	110,000	120,000	50,000	10	20.6	311	30.3
	12Z	SRR	1200	87,900	------	62,500	70,000	22,500	16.5	21.3	-------	23.8
	14Z	SRR	1200	89,500	------	70,000	73,500	40,000	14	23.0	-------	22.1
	13Z	SRR	1350	65,375	------	48,500	53,000	17,500	31	45.3	-------	20.3
	15X	SRC	1350	63,875	------	53,000	57,000	22,500	27	35.0	-------	19.6
	c2Y	CRR	1500	43,250	------	32,500	36,000	------	20	29.8	-------	14.0
	c1Z	SRR	1500	43,000	------	30,200	35,750	------	31	38.2	-------	19.4
NR-74B-Q	15Y	CRR	75	117,500	37,500	53,000	59,000	22,500	30.5	27.2	211	27.6
	16Z	SRC	75	121,500	35,000	48,500	55,000	22,500	42	41.3	215	23.5
	17Y	CTR	75	119,000	40,000	53,500	59,000	25,000	38	37.2	223	29.4
	17X	STR	75	121,000	30,000	47,000	57,000	17,500	40	38.5	218	27.6
	14Z	SRR	1200	82,000	------	41,500	44,000	20,000	12	17.7	-------	22.2
	15Z	SRR	1350	71,250	------	41,500	46,000	22,500	11	13.0	-------	22.2
NR-74B-QA	16Y	CRC	75	130,500	45,000	63,500	70,500	25,000	17	18.2	259	27.8
	16X	SRC	1200	81,600	------	46,000	49,000	27,500	27	31.2	-------	23.8
	13X	SRR	1350	65,750	------	43,500	46,000	20,000	25	30.4	-------	22.8
	c1Y	CRR	1500	44,500	------	35,700	38,250	------	22.7	27.2	-------	18.0
	c2Z	SRR	1500	44,250	------	34,400	37,450	------	13.3	15.9	-------	19.5

[a] Heat treatments:
NR-74B-F: As-forged; 16 hr at 1400° F.
NR-74B-Q: 2300° F water-quenched.
NR-74B-QA: 2300° F water-quenched; 16 hr at 1400° F.

[b] CRR center-plane radial specimen near rim of disc.
SRR surface-plane radial specimen near rim of disc.
CTR center-plane tangential specimen near rim of disc.
STR surface-plane tangential specimen near rim of disc.
SRC surface-plane radial specimen near center of disc.
CRC center-plane radial specimen near center of disc.

[c] NDRC and Navy data at 1500° F.

NACA

TABLE II

CHARPY NOTCH-BAR IMPACT RESISTANCE AT ROOM TEMPERATURE, 1200°, 1350°, and 1500° F FOR S-590 ALLOY DISCS NR-74B

[NDRC and Navy data]

Disc (1)	Specimen number	Specimen location	Test temperature (°F)	Charpy impact strength (ft-lb)
NR-74B-F	5C	Interior	Room	5
	7C	Interior		5
	8B	Interior		5
	5A	Surface		6
	7F	Surface		7
NR-74B-F	5D	Interior	1200	8
	7D	Interior		8
	8E	Interior		8
	5F	Surface		13
	10A	Surface		10
NR-74B-F	8D	Interior	1350	8
	6D	Interior		10
	10E	Interior		8
	6A	Surface		14
	8A	Surface		13
	8F	Surface		13
NR-74B-F	6C	Interior	1500	12
	8C	Interior		10
	5B	Interior		13
	6F	Surface		18
	7A	Surface		17
	10A	Surface		14
NR-74B-QA	8D	Interior	Room	6
	7E	Interior		10
	8F	Surface		10
NR-74B-QA	9C	Interior	1200	10
	8B	Interior		14
	9A	Surface		20
	9F	Surface		16
NR-74B-QA	9D	Interior	1350	12
	7C	Interior		12
	9B	Interior		16
	10A	Surface		24
	7A	Surface		20
NR-74B-QA	10D	Interior	1500	13
	7D	Interior		13
	10B	Interior		16
	10F	Surface		25
	8A	Surface		29

[1]Heat treatment:
NR-74B-F: As-forged; 16 hr at 1400° F.
NR-74B-QA: 2300° F water-quenched; 16 hr at 1400° F.

TABLE III

RUPTURE TEST DATA AT 1200°, 1350°, and 1500° F FOR S-590 ALLOY DISCS HR-74B

Disc (a)	Specimen number	Specimen location (b)	Test temperature (°F)	Stress (psi)	Rupture time (hr)	Elongation in 1 in. (percent)	Reduction of area (percent)	Minimum creep rate (percent/hr)
[c]HR-74B-F	17Y	CRR	1200	55,000	69.5	21	20.6	------
	17Y	CRR		50,000	150	17	21.2	------
	17Z	SRR		[d]50,000	[e]1288	-----	----	------
	17Y	CRR		45,000	372.5	[f]9	14.4	0.0102
	12Y	CRR		40,000	894	6	7.3	.0036
	17Z	SRR		[d]40,000	1396	7	7.1	.0018
	12Y	CRR		37,000	2310	7	12.7	.0013
	12X	SRR		[d]37,000	[e]2376	-----	----	.0012
	17X	SRR		52,500	256	[f]15	15.0	------
	12Y-C	CRC		52,500	161	17	15.6	------
[c]HR-74B-Q	19Y	CRR	1200	55,000	59	4	7.9	------
	19Y	CRR		50,000	74	6	8.5	------
	19Y	CRR		45,000	493	[f]4	7.3	.0046
	14Y	CRR		42,000	495	[f]5	8.5	.0068
	18Y	CRR		40,000	937	[f]5	5.0	.0026
	19X	SRR		52,500	14	6	13.6	------
	19X	SRR		50,000	111	4	10.9	------
	14YC	CRC		50,000	228	[f]3	15.3	------
	17Z	STR		50,000	10	[f]8	6.2	------
[c]HR-74B-QA	13Y	CRR	1200	55,000	60	11	13.8	------
	20Y	CRR		50,000	153	13	16.7	------
	20Y	CRR		45,000	640	[f]9	13.3	.0086
	13Y	CRR		42,000	878	12	13.3	.0072
	13X	SRR		[d]40,000	1596	13	19.1	.0036
	20X	SRR		52,000	95	15	17.8	------
[c]HR-74B-F	17Y	CRR	1350	30,000	60	12	14.4	------
	17Y	CRR		25,000	180	8	11.5	.0186
	12X	SRR		[d]25,000	183	11	10.9	.0186
	17Y	CRR		20,000	676	[f]7	4.4	.0030
	12X	SRR		[d]20,000	[f]196	[f]3.5	6.4	.0054
	12Y	CRR		17,000	1291	4	2.3	.0006
	17Z	SRR		[d]17,000	995	[f]5	2.4	.0006
	17X	SRR		27,500	86	6	10.9	------
	12Y-C	CRC		27,500	198	17.5	18.9	------
[c]HR-74B-Q	19Y	CRR	1350	33,000	86	10	15.6	------
	19Y	CRR		30,000	252	11	15.0	------
	14Y	CRR		27,000	204	8	8.0	------
	14Y	CRR		25,000	951	11	17.8	.0048
	14X	SRR		32,000	165.5	[f]4	5.0	------
	14Y-C	CRC		32,000	373	5	7.3	------
[c]HR-74B-QA	13Y	CRR	1350	35,000	45.5	13	17.8	------
	13Y	CRR		30,000	198	12.5	16.0	------
	13Y	CRR		27,000	167	8	15.6	------
	13Y	CRR		25,000	1121	[f]13	17.8	.0044
	13X	SRR		[d]25,000	[e]844	-----	----	.0050
	20X	SRR		32,000	97	[f]18	18.3	------
[g]HR-74B-F	9A	SRR	1500	20,000	29	6.5	12.8	.10
	9D	CRR		16,000	59	9.0	8.5	.05
	9E	CRR		11,000	124	12.0	17.5	.024
	2Z	SRR		[h]10,000	264	10.0	----	.0083
	9F	SRR		6,000	1018	5.0	9.4	.0018
[g]HR-74B-QA	11A	SRR	1500	20,000	76	18.0	25.5	------
	11F	SRR		20,000	104	30.0	33.9	.027
	11E	CRR		19,000	203	32.0	33.6	------
	11C	CRR		18,000	372	27.0	28.8	.0065
	11B	CRR		16,000	642	20.0	31.6	.0038
	11D	CRR		15,000	1000	16.5	25.5	.0014

[a]Heat treatments:
HR-74B-F As-forged; 16 hr at 1400° F.
HR-74B-Q 2300° F water-quenched.
HR-74B-QA 2300° F water-quenched; 16 hr at 1400° F.

[b]CRR center-plane radial specimen near rim of disc.
SRR surface-plane radial specimen near rim of disc.
CRC center-plane radial specimen near center of disc.
STR surface-plane tangential specimen near rim of disc.

[c]NACA data. (Specimens were 0.160 in. in diameter with a gage length of 1 in. unless indicated otherwise.)

[d]Test on 0.250-in.-diameter specimen with precision extensometers.

[e]Discontinued at this time.

[f]Fractured in gage mark.

[g]SWDEC and Navy data. (Specimens were 0.250 in. in diameter with gage length of 1.3 in.)

[h]Test on 0.505-in.-diameter specimen.

TABLE IV

RUPTURE TEST CHARACTERISTICS AT 1200°, 1350°, AND 1500° F OF S-590 ALLOY DISCS NR-74B

Disc (a)	Temperature (°F)	Rupture strength: Stress (psi) for rupture in – 10 hr	100 hr	1000 hr	2000 hr	Rupture ductility: Estimated elongation (percent) to rupture in – 10 hr	100 hr	1000 hr	2000 hr
[b]NR-74B-F	1200	[c]69,000	52,500	40,000	37,000	--	20	7	7
[b]NR-74B-Q		[c]66,000	51,000	40,000	37,000	--	6	5	--
[b]NR-74B-QA		[c]66,000	52,000	42,000	38,500	--	12	12	12
[b]NR-74B-F	1350	[c]42,000	27,500	18,000	16,000	--	10	5	--
[b]NR-74B-Q		[c]42,000	32,500	25,000	23,000	--	10	11	--
[b]NR-74B-QA		[c]41,000	32,000	25,000	23,500	15	12	13	--
[d]NR-74B-F	1500	29,000	13,100	6,000	4,800	7	12	5	--
[d]NR-74B-QA		------	20,000	15,000	13,100	--	30	16	--

NACA

[a]Heat treatments:
NR-74B-F As-forged; 16 hr at 1400° F.
NR-74B-Q 2300° F water-quenched.
NR-74B-QA 2300° F water-quenched; 16 hr at 1400° F.

[b]NACA data.

[c]Estimated strength by extrapolation.

[d]NDRC and Navy data.

TABLE V

DATA ON STRESS AND TIME FOR TOTAL DEFORMATION AT 1200° F FOR S-590 ALLOY DISCS NR-74B

[NACA data]

Disc (a)	Specimen number	Stress (psi)	Initial deformation (percent)	Time (hr) for total deformations of –						Transition to third-stage creep	
				0.1 percent	0.2 percent	0.5 percent	1 percent	2 percent	5 percent	Time (hr)	Deformation (percent)
NR-74B-F	13Y	25,000	0.107	--	320	-------	---	----	----	----	---
	15Y	25,000	.103	--	270	-------	---	----	----	----	---
	13X	35,000	.150	--	4	612	---	----	----	----	---
	12Y	37,000	.165	--	---	6.5	286	1150	2265	1720	2.8
	12X	37,000	.190	--	2	122	610	1740	----	----	---
	12Y	40,000	.180	--	---	21.0	124	407	835	560	2.7
	17Z	40,000	.220	--	---	23	236	790	----	790	2.0
	17Y	45,000	.205	--	---	11	33	111	277	140	2.3
	17Y	50,000	.230	--	---	3	13	35	96	50	2.6
	17Y	55,000	.260	--	---	-------	---	16	37	----	---
NR-74B-Q	15X	35,000	.199	--	---	187	590	----	----	----	---
	18Y	40,000	.250	--	---	25	168	390	----	890	3.5
	14Y	42,000	.310	--	---	4	48	200	----	340	3.0
	19Y	45,000	.440	--	---	0.5	27	185	----	480	3.6
	19Y	50,000	.800	--	---	-------	---	20	----	----	---
NR-74B-QA	13Y	25,000	.108	--	130	[b]1250	---	----	----	----	---
	13Z	35,000	.158	--	5	102	583	----	----	----	---
	13X	40,000	.240	--	---	13	55	235	925	790	4.2
	13Y	42,000	.215	--	---	7	29	125	525	505	4.8
	20Y	45,000	.270	--	---	2	20	82	390	405	5.1
	20Y	50,000	.430	--	---	-------	3	17	80	80	5.0

[a]Heat treatments:
NR-74B-F As-forged; 16 hr at 1400° F.
NR-74B-Q 2300° F water-quenched.
NR-74B-QA 2300° F water-quenched; 16 hr at 1400° F.

[b]By extrapolation.

NACA

TABLE VI

DATA ON STRESS AND TIME FOR TOTAL DEFORMATION AT 1350° F FOR S-590 ALLOY DISCS NR-74B

Disc (a)	Specimen number	Stress (psi)	Initial deformation (percent)	Time (hr) for total deformations of –						Transition to third-stage creep	
				0.1 percent	0.2 percent	0.5 percent	1 percent	2 percent	5 percent	Time (hr)	Deformation (percent)
NR-74B-F	[b]1Y	12,000	0.052	13	158	1530	----	----	---	---	----
	[b]2X	15,000	.092	5	78	522	1282	1825	---	850	0.66
	[c]12Y	17,000	.085	--	6	44	480	920	---	600	1.2
	[c]17Z	17,000	.089	--	6	100	510	850	---	600	1.2
	[b]3X	20,000	.099	1	10	71	285	590	---	375	1.28
	[c]17Y	20,000	.100	--	-----	[d]2	20	260	655	260	2.0
	[c]12X	20,000	.115	--	-----	4	65	----	---	---	----
	[c]17Y	25,000	.130	--	-----	-----	11	58	150	65	2.1
	[c]12X	25,000	.154	--	-----	-----	13	68	160	85	2.4
	[c]17Y	30,000	.160	--	-----	-----	3	14	42	---	----
NR-74B-Q	[c]14Y	25,000	.115	--	2.5	9	28	72	685	740	5.2
	[c]14Y	27,000	.125	--	-----	[d]2	9	50	170	170	5
	[c]19Y	30,000	.145	--	-----	[d]4	15	50	190	150	4
	[c]19Y	33,000	.175	--	-----	[d]4	13	31	65	---	----
NR-74B-QA	[b]2Y	12,000	.049	22	275	-----	----	----	---	---	----
	[b]1X	15,000	.085	6	58	[d]3030	----	----	---	---	----
	[b]3X	20,000	[e].125	--	12	103	1765	----	---	---	----
	[b]3Z	23,000	.142	--	1.5	42	235	----	---	460	1.35
	[c]13Y	25,000	.110	--	2	16	52	220	725	600	3.7
	[c]13X	25,000	.142	--	2	11	46	186	---	---	----
	[c]13Y	27,000	.120	--	-----	4	11	30	142	98	3.7
	[c]13Y	30,000	.135	--	-----	6	14	32	133	90	3.7

[a]Heat treatments:
NR-74B-F As-forged; 16 hr at 1400° F.
NR-74B-Q 2300° F water-quenched.
NR-74B-QA 2300° F water-quenched; 16 hr at 1400° F.

[b]NDRC and Navy data.

[c]NACA data.

[d]Estimated.

[e]Contraction upon release of load.

TABLE VII

DATA ON STRESS AND TIME FOR TOTAL DEFORMATION AT 1500° F FOR S-590 ALLOY DISCS NR-74B

[NDRC and Navy data]

Disc (a)	Specimen number	Stress (psi)	Initial deformation (percent)	Time (hr) for total deformations of-						Transition to third-stage creep	
				0.1 percent	0.2 percent	0.5 percent	1 percent	2 percent	5 percent	Time (hr)	Deformation (percent)
NR-74B-F	9A	20,000	-----	---	-----	1.7	6	16	28	15.5	1.95
	9D	16,000	-----	---	-----	4.5	13.5	31	54	24	1.56
	9E	11,000	-----	---	2	11	28	64	101	48	1.42
	2Z	10,000	0.069	1	5	35	86	145	250	74	0.92
	9F	6,000	-----	4	22	132	392	700	---	464	1.17
NR-74B-QA	11F	20,000	-----	---	-----	10	24	42	69	14	.60
	11C	18,000	-----	---	-----	20	72	119	220	40	.62
	11B	16,000	-----	---	6	70	180	306	474	155	.85
	11D	15,000	-----	---	5	58	325	545	787	300	.94
	4X	12,000	.077	3	25	1270	[b]3400	---	---	1700	.58
	1Z	10,000	.068	72	456	1800	-------	---	---	------	----
	2X	8,000	.036	430	[b]4000	------	-------	---	---	------	----

[a]Heat treatments:
NR-74B-F As-forged; 16 hr at 1400° F.
NR-74B-QA 2300° F water-quenched; 16 hr at 1400° F.

[b]Estimated.

TABLE VIII

TIME-DEFORMATION AND CREEP STRENGTHS AT 1200° F

FOR S-590 ALLOY DISCS NR-74B

[NACA data]

Disc (a)	Total deformation (percent)	Stress (psi) to cause total deformation in –					Creep strength (based on creep rates at 1000 hr) (psi)	
		1 hr	10 hr	100 hr	1000 hr	2000 hr	0.00010 percent/hr	0.00001 percent/hr
NR-74B-F	0.2	38,000	33,000	28,500	22,000	[b]20,500	27,500	------
NR-74B-Q	.2	-------	------	-------	-------	-------	------	------
NR-74B-QA	.2	[b]40,000	33,000	26,000	[b]18,500	-------	23,000	------
NR-74B-F	.5	-------	44,000	38,000	32,000	[b]30,000	------	------
NR-74B-Q	.5	-------	41,500	36,200	31,000	-------	------	------
NR-74B-QA	.5	47,000	40,500	33,800	27,000	[b]25,000	------	------
NR-74B-F	1.0	-------	50,000	42,000	34,300	32,000	------	------
NR-74B-Q	1.0	-------	47,000	40,500	34,000	[b]32,000	------	------
NR-74B-QA	1.0	-------	46,500	39,500	33,000	[b]31,000	------	------
NR-74B-F	Transition	-------	------	47,000	39,000	36,000	------	------
NR-74B-Q	Transition	-------	------	[b]50,000	39,000	-------	------	------
NR-74B-QA	Transition	-------	------	49,000	39,000	36,000	------	------

[a]Heat treatments:

NR-74B-F As-forged; 16 hr at 1400° F.
NR-74B-Q 2300° F water-quenched.
NR-74B-QA 2300° F water-quenched; 16 hr at 1400° F.

[b]Estimated strength by extrapolation.

TABLE IX

TIME-DEFORMATION AND CREEP STRENGTHS AT 1350° F

FOR S-590 ALLOY DISCS NR-74B

[NACA, NDRC, and Navy data]

Disc (a)	Total deformation (percent)	Stress (psi) to cause total deformation in –					Creep strength (based on minimum rates) (psi)	
		1 hr	10 hr	100 hr	1000 hr	2000 hr	0.00010 percent/hr	0.00001 percent/hr
NR-74B-F	0.1	20,000	12,800	------	------	------	10,600	------
NR-74B-Q	.1	------	------	------	------	------	------	------
NR-74B-QA	.1	19,000	13,800	------	------	------	16,400	12,100
NR-74B-F	.2	------	[b]18,600	13,100	[b]8,000	------	------	------
NR-74B-Q	.2	------	[b]16,000	------	------	------	------	------
NR-74B-QA	.2	26,400	20,600	14,700	8,700	[b]7,000	------	------
NR-74B-F	.5	------	21,000	17,000	13,000	11,500	------	------
NR-74B-Q	.5	------	24,000	------	------	------	------	------
NR-74B-QA	.5	30,000	25,700	21,400	17,000	15,700	------	------
NR-74B-F	1.0	------	25,500	20,500	15,500	14,000	------	------
NR-74B-Q	1.0	------	33,000	------	------	------	------	------
NR-74B-QA	1.0	------	27,700	24,100	20,800	19,800	------	------
NR-74B-F	Transition	------	-------	24,500	14,500	11,700	------	------
NR-74B-Q	Transition	------	-------	31,000	14,000	------	------	------
NR-74B-QA	Transition	------	-------	29,000	22,500	------	------	------

[a]Heat treatments:

NR-74B-F As-forged; 16 hr at 1400° F.
NR-74B-Q 2300° F water-quenched.
NR-74B-QA 2300° F water-quenched; 16 hr at 1400° F.

[b]Estimated strength by extrapolation.

TABLE X

TIME-DEFORMATION AND CREEP STRENGTHS AT 1500° F

FOR S-590 ALLOY DISCS NR-74B

[NDRC and Navy data]

Disc (a)	Total deformation (percent)	Stress (psi) to cause total deformation in –					Creep strength (based on minimum rates) (psi)	
		1 hr	10 hr	100 hr	1000 hr	2000 hr	0.00010 percent/hr	0.00001 percent/hr
NR-74B-F	0.1	10,000	[b]6,800	------	------	------	[b]2,800	----
NR-74B-QA	.1	[b]13,600	11,500	9,400	[b]7,300	------	10,000	7100
NR-74B-F	.2	13,500	7,800	------	------	------	------	----
NR-74B-QA	.2	-------	14,000	11,000	9,200	8,600	------	----
NR-74B-F	.5	-------	12,700	6,500	------	------	------	----
NR-74B-QA	.5	-------	19,400	14,800	11,600	10,500	------	----
NR-74B-F	1.0	-------	17,300	9,000	[b]4,000	------	------	----
NR-74B-QA	1.0	-------	------	17,200	13,600	12,700	------	----
NR-74B-F	Transition	-------	------	9,300	[b]4,200	------	------	----
NR-74B-QA	Transition	-------	20,400	16,700	12,800	11,800	------	----

[a]Heat treatments:

NR-74B-F As-forged; 16 hr at 1400° F.
NR-74B-QA 2300° F water-quenched; 16 hr at 1400° F.

[b]Estimated strength by extrapolation.

TABLE XI

CREEP TEST DATA AT 1200°, 1350°, AND 1500° F FOR S-590 ALLOY DISCS NR-74B

Disc (a)	Specimen number	Test temperature (°F)	Stress (psi)	Duration (hr)	Deformation upon application of load (percent)	Creep rate (percent/hr) at –				Total deformation (percent) at –			
						500 hr	1000 hr	1500 hr	2000 hr	500 hr	1000 hr	1500 hr	2000 hr
NR-74B-F	[b]13Y	1200	25,000	1108	0.107	0.000082	0.000066	--------	--------	0.217	0.257	-----	------
	[b]15Y	1200	25,000	960	.103	.000082	.000066	--------	--------	.217	-----	-----	------
	[b]13X	1200	35,000	1002	.150	.00028	.00027	--------	--------	.469	.605	-----	------
NR-74B-Q	[b]15X	1200	35,000	770	.199	.00095	[c].00090	--------	--------	.915	[c]1.163	-----	------
NR-74B-QA	[b]13Y	1200	25,000	1009	.108	.00026	.00025	--------	--------	.305	.435	-----	------
	[b]13Z	1200	35,000	1002	.158	.00090	.00087	--------	--------	.925	1.370	-----	------
NR-74B-F	[d]3X	1350	20,000	(e)	.099	[f].0032	--------	--------	--------	1.65			
	[d]2X	1350	15,000	1872	.092	.00064	.00058	0.0013	[g]0.0025	.483	.760	1.22	[g]2.00
	[d]1Y	1350	12,000	2059	.052	.00022	.00019	.00018	.00017	.301	.405	.497	.586
NR-74B-QA	[d]3Z	1350	23,000	[h]886	.142	.0015	--------	--------	--------	1.42			
	[d]3X	1350	20,000	2016	.125	.00026	.00013	.00012	.00012	.809	.907	.969	1.029
	[d]1X	1350	15,000	2282	.085	.00011	.00008	.00008	.00005	.323	.385	.420	.440
	[d]2Y	1350	12,000	2135	.049	.00007	.000019	.000019	.000009	.219	.237	.246	.253
NR-74B-F	[d]1X	1500	8,000	[i]743	.046	[i].00185	--------	--------	--------	1.021	------	-----	------
NR-74B-QA	[d]4X	1500	12,000	2136	.077	.00020	.00017	.00017	.00020	.375	.457	.536	.640
	[d]1Z	1500	10,000	2064	.068	.00027	.00022	.00022	.00025	.228	.330	.430	.620
	[d]2X	1500	8,000	2039	.036	.000044	.000034	.000028	.000024	.104	.125	.140	.152

[a]Heat treatments:
NR-74B-F As-forged; 16 hr at 1400° F.
NR-74B-Q 2300° F water-quenched.
NR-74B-QA 2300° F water-quenched; 16 hr at 1400° F.

[b]NACA data.

[c]At 770 hr.

[d]NDRC and Navy data.

[e]Broke in threads shortly after 744 hr.

[f]Minimum creep rate, measured between 75 and 400 hr; 0.00255 percent/hr.

[g]At 1872 hr.

[h]Discontinued at 886 hr with 2.78-percent deformation. Minimum creep rate 0.0015 percent/hr between 250 and 500 hr.

[i]Discontinued at 743 hr with 1.56-percent deformation. Minimum creep rate between 150 and 350 hr; 0.00166 percent/hr.
Data from this test were not used for the design curves.

TABLE XII

EFFECT OF CREEP TESTING ON THE ROOM-TEMPERATURE PHYSICAL PROPERTIES OF S-590 ALLOY DISCS NR-74B

Disc (a)	Specimen number	Prior testing conditions			Residual room-temperature properties								
		Temperature (°F)	Stress (psi)	Time (hr)	Tensile strength (psi)	Offset yield strength (psi)			Proportional limit (psi)	Elongation in 2 in. (percent)	Reduction of area (percent)	Izod impact strength (psi)	Vickers hardness
						0.02 percent	0.1 percent	0.2 percent					
NR-74B-F	(b)	(c)	(c)	(c)	129,050	70,750	90,000	98,250	42,500	8	10.3	---------	309
	[d]14Y	(c)	(c)	(c)	-------	------	------	------	------	----	----	[e]2, 5	---
	[f]3Y, 4X	(c)	(c)	(c)	-------	------	------	------	------	----	----	[g]7, 6, 5	268
	[d]13Y	1200	25,000	1108	127,000	61,000	85,000	94,500	27,500	6	7.3	---------	---
	[d]13X	1200	35,000	1002	-------	------	------	------	------	----	----	[e]2, 2	278
	[f]1Y	1350	12,000	2059	110,500	58,000	76,000	85,000	40,500	.7	1.4	---------	---
	[f]2X	1350	15,000	1872	-------	------	------	------	------	----	----	[g]1, 2	245
	[f]1X	1500	8,000	743	105,000	53,500	71,200	80,800	37,900	1.5	1.6	---------	---
	(h)	1500	------	----	-------	------	------	------	------	----	----	---------	---
NR-74B-Q	(b)	(c)	(c)	(c)	119,500	36,250	50,750	57,000	22,500	36	34.3	---------	235
	[d]14X	(c)	(c)	(c)	-------	------	------	------	------	----	----	[e]24, 32	---
	[d]15X	1200	35,000	770	127,500	58,000	81,000	87,500	25,000	6.5	5.7	---------	---
	(h)	1200	------	----	-------	------	------	------	------	----	----	---------	---
NR-74B-QA	(b)	(c)	(c)	(c)	130,500	45,000	63,500	70,500	25,000	17	18.2	---------	267
	[d]16Y	(c)	(c)	(c)	-------	------	------	------	------	----	----	[e]9, 28	---
	[f]3Y, 4Z	(c)	(c)	(c)	-------	------	------	------	------	----	----	[g]7, 8, 6	282
	[d]13Y	1200	25,000	1009	131,000	60,000	78,000	85,000	37,500	5.5	6.4	---------	---
	[d]13Z	1200	35,000	1002	-------	------	------	------	------	----	----	[e]5, 4	284
	[f]2Y	1350	12,000	2135	132,500	57,500	72,000	79,600	39,000	3.3	4.5	---------	---
	[f]1X	1350	15,000	2282	-------	------	------	------	------	----	----	[g]4, 4	319
	[f]1Z	1500	10,000	2064	116,000	43,000	55,000	62,500	31,500	4.5	4.9	---------	---
	[f]4X	1500	12,000	2136	-------	------	------	------	------	----	----	[g]2, 3	295

[a]Heat treatments:
NR-74B-F As forged; 16 hr at 1400° F.
NR-74B-Q 2300° F water-quenched.
NR-74B-QA 2300° F water-quenched; 16 hr at 1400° F.

[b]Average of tests on center- and surface-plane radial specimens.

[c]Original condition.
[d]NACA data.
[e]Specimens were 0.365-in. square with a 0.50-in.-deep V-notch.
[f]NDRC and Navy data.
[g]Specimens were 0.450-in.-diameter, V-notch.
[h]No specimen available for impact and hardness tests.

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TABLE XIII

RESULTS FROM ALLEGHENY-LUDLUM STEEL CORPORATION AND COMPARATIVE NACA, NDRC, AND NAVY

RESULTS ON THE S-590 ALLOY DISCS HR-74B

Data source (1)	Treatment	Room-temperature tensile properties					Rupture properties					
		Tensile strength (psi)	0.02-percent-offset yield strength (psi)	Elongation (percent)	Reduction of area (percent)	Brinell hardness	Temperature (°F)	Stress (psi)	Time (hr)	Elongation (percent)	Reduction of area (percent)	Brinell hardness
					As-forged disc							
AL	As-forged	143,000 141,500 140,500	92,500 85,000 82,500	3.5 12.5 7	7.7 29.8 13.1	293-311	1350	30,000	25	6	18.4	293
AL	As-forged; 16 hr at 1400° F	133,500	72,500	13	19.2	302	1200 1200	50,000 45,000	134.5 397	17.5 13	30 16	297 277
UM		129,050	70,750	8	10.3	267-311	1200 1200	50,000 45,000	150 372.5	17 9	21.2 14.4	--- ---
AL	Forged; 16 hr at 1500° F	132,500	55,000	13	10.1	285	1500 1500	20,000 17,500	9 23	15 23	27 22	277 285
					Solution-treated disc							
AL	2300° F $3\frac{1}{4}$ hr water-quenched	125,000	32,500	39.5	34.3	229-241	1200	45,000	178	3	4	223
UM		119,500	36,250	36	34.3	211-223	1200	45,000	493	4	7.3	---
					Solution-treated and aged disc							
AL	2300° F water-quenched; 16 hr at 1400° F	134,000	45,000	22	18.8	255	1350 1350 1350	35,000 30,000 25,000	42 185 923	24 26.5 19	23 29.4 23	302 302 302
UM		130,500	45,000	17	18.2	259	1350 1350	30,000 25,000	252 951	11 11	15 17.8	--- ---
B		-------	------	----	----	-------	1500 1500	20,000 15,000	76 1000	18 16.5	25.5 25.5	--- ---
AL	2300° F water-quenched; 16 hr at 1500° F	-------	------	----	----	-------	1500 1500 1500	20,000 17,500 15,000	104 238 747	29.5 36 31	41.5 38 39	277 285 277

[1]AL data supplied by Allegheny-Ludlum Steel Corp.
UM University of Michigan (NACA) data.
B Battelle (NDRC and Navy) data.
All Allegheny-Ludlum data were on specimens representing chords from the discs. All University of Michigan and Battelle data were on radial specimens.

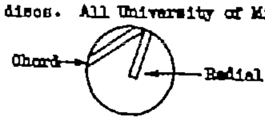

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TABLE XIV

COMPARATIVE PROPERTIES OF BAR STOCK AND DISCS OF S-590 ALLOY

Form	Treatment	Tensile properties					Rupture characteristics				
		Temperature (°F)	Tensile strength (psi)	Offset yield strength (psi)		Elongation (percent)	Temperature (°F)	Rupture strength (psi)		Estimated rupture elongation (percent)	
				0.02 percent	0.2 percent			100 hr	1000 hr	100 hr	1000 hr
Disc (NR-74B-F)	Forged and aged	75	129,050	70,750	98,250	8	1350	27,500	18,000	10	5
Disc (NR-74B-Q)	Solution-treated	75	119,500	36,250	57,000	36	1350	32,500	25,000	10	11
Disc (NR-74B-QA)	Solution-treated and aged	75	130,500	45,000	70,500	17	1350	32,000	25,000	12	13
Bar stock[a]	Solution-treated and aged	75	159,500	56,750	88,250	9.5	[a]1350	31,000 32,000	24,000 26,000	-- 35	-- 40
Disc (NR-74B-F)	Forged and aged	1350	64,625	------	55,000	29	1500	13,100	6,000	12	5
Disc (NR-74B-QA)	Solution-treated and aged	1350	65,750	------	46,000	25	1500	20,000	15,000	30	16
Bar stock[a]	Solution-treated and aged	1350	65,875	------	57,500	28	[b]1500	19,000 21,000	14,000 15,500	8 23	10 25

Form	Treatment	Temperature (°F)	Time-deformation strengths									
			100-hr deformation strengths (psi)					1000-hr deformation strengths (psi)				
			0.1 percent	0.2 percent	0.5 percent	1 percent	Transition	0.1 percent	0.2 percent	0.5 percent	1 percent	Transition
Disc (NR-74B-F)	Forged and aged	1500	------	------	6,500	9,000	9,300	------	------	------	4,000	4,200
Disc (NR-74B-QA)	Solution-treated and aged	1500	9,400	11,000	14,800	17,200	16,700	7,300	9,200	11,600	13,600	12,800
Bar stock[b]	Solution-treated and aged	1500	10,300	13,200	17,300	18,700	17,600	8,000	10,600	13,100	14,000	------

[a]Unpublished data from the University of Michigan.
[b]Data from reference 11.

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TABLE IV

COMPARISON OF ROOM-TEMPERATURE AND HIGH-TEMPERATURE PROPERTIES OF SEVERAL LARGE FORGED DISCS OF S-590 AND S-816 ALLOYS

Test temperature, °F	Room temperature				1200				1350				1500			
Alloy	S-590		[b]S-816		S-590		[b]S-816		S-590		[b]S-816		S-590		[b]S-816	
Disc[a]	NR-74B-F	NR-74B-QA	NR-76B-F	NR-76B-Q	NR-74B-F	NR-74B-QA	NR-76B-F	NR-76B-Q	NR-74B-F	NR-74B-QA	NR-76B-F	NR-76B-Q	NR-74B-F	NR-74B-QA	NR-76B-F	NR-76B-Q
Short-time properties:																
Charpy impact strength, ft-lb	5	9	25	19	9	15	43	43	11	17	47	40	13	20	43	43
Izod impact strength, ft-lb	6	7	18	19												
Tensile strength, psi	129,050	130,500	150,000	144,000	88,700	81,600	120,000	106,000	64,625	65,750	88,000	83,000	43,125	44,400	59,000	60,000
0.1-percent-offset yield strength, psi	90,000	63,500	79,000	70,000	66,250	46,000	63,000	56,000	50,750	43,500	56,000	52,000	31,350	35,050	46,000	49,000
0.2-percent-offset yield strength, psi	98,250	70,500	85,000	76,000	71,750	49,000	67,000	58,000	55,000	46,000	59,000	55,000	35,900	37,850	49,000	51,000
Elongation, percent	8	17	21	30	15	27	16	12	29	25	23	28	25	18	17	17
Rupture strengths, psi:																
10-hr	-------	-------	-------	-------	[c]69,000	[c]66,000	[c]78,000	[c]84,000	[c]42,000	[c]41,000	52,000	[c]53,000	[c]29,000	------	[c]31,000	[c]29,500
100-hr	-------	-------	-------	-------	52,500	52,000	62,000	66,000	27,500	32,000	37,500	39,000	13,100	20,000	20,500	22,800
1000-hr	-------	-------	-------	-------	40,000	42,000	50,000	53,000	18,000	25,000	27,000	29,000	6,000	15,000	13,700	17,500
Rupture elongations, percent[c]:																
100-hr	-------	-------	-------	-------	20	12	10	7	10	12	10	12	12	30	5	7
1000-hr	-------	-------	-------	-------	7	12	10	7	5	13	10	10	5	16	4	4
Creep strengths, psi:																
0.0001 percent/hr	-------	-------	-------	-------	27,500	23,000	28,000	28,000	10,600	16,400	19,500	19,000	[c]2,800	10,000	11,000	13,500
0.00001 percent/hr	-------	-------	-------	-------	------	------	[c]18,000	[c]16,000	------	12,100	13,000	10,500	------	7,100	8,500	7,500
100-hr deformation strengths, psi:																
0.1-percent deformation	-------	-------	-------	-------	------	------	------	[c]19,500	------	------	13,000	13,000	------	9,400	9,000	9,000
0.2-percent deformation	-------	-------	-------	-------	28,500	26,000	31,500	34,500	13,100	14,700	22,000	20,000	------	11,000	13,800	14,000
0.5-percent deformation	-------	-------	-------	-------	38,000	33,800	43,000	46,000	17,000	21,400	28,000	27,000	6,500	14,800	17,000	19,000
1.0-percent deformation	-------	-------	-------	-------	43,000	39,500	48,000	52,500	20,500	24,100	31,000	30,000	9,000	17,800	18,500	21,000
Transition	-------	-------	-------	-------	47,000	49,000	59,500	[c]64,000	24,500	29,000	35,500	36,000	9,300	16,700	18,000	20,200
1000-hr deformation strengths, psi:																
0.1-percent deformation	-------	-------	-------	-------	------	------	------	-------	------	------	[c]10,000	[c]9,000	-------	[c]7,300	[c]5,500	[c]5,500
0.2-percent deformation	-------	-------	-------	-------	22,000	[c]18,500	24,500	25,500	[c]8,000	8,700	16,500	15,000	-------	9,200	9,600	10,000
0.5-percent deformation	-------	-------	-------	-------	32,000	27,000	33,500	37,000	13,000	17,000	24,500	21,500	-------	11,600	11,200	[c]14,700
1.0-percent deformation	-------	-------	-------	-------	34,300	33,000	38,000	[c]43,000	15,500	20,800	[c]26,500	[c]23,500	[c]4,000	13,600	12,000	[c]16,000
Transition	-------	-------	-------	-------	39,000	39,000	48,000	52,000	14,500	22,500	28,000	27,000	[c]4,200	12,800	12,000	[c]16,000
					After creep testing at 1200° F				After creep testing at 1350° F				After creep testing at 1500° F			
Residual room-temperature properties:																
Izod impact strength, ft-lb	-------	-------	-------	-------	-------	-------	11	5.5	2	4	7	7.8	------	2	5.5	4.8
Tensile strength, psi	-------	-------	-------	-------	127,000	131,000	139,000	138,000	110,500	132,500	136,500	133,500	105,000	116,000	123,000	119,000
0.1-percent-offset yield strength, psi	-------	-------	-------	-------	85,000	78,000	79,000	81,000	76,000	72,000	82,000	75,500	71,200	55,000	67,000	65,000
0.2-percent-offset yield strength, psi	-------	-------	-------	-------	94,500	85,000	87,000	88,000	85,000	79,600	89,000	81,000	80,800	62,500	75,500	71,500
Elongation, percent	-------	-------	-------	-------	6	6	8.0	8.5	1	3	9.0	10.7	1.5	5	7.4	7.0

[a]Heat treatments:

NR-74B-F As-forged and aged disc; 16 hr at 1400° F; air-cool.

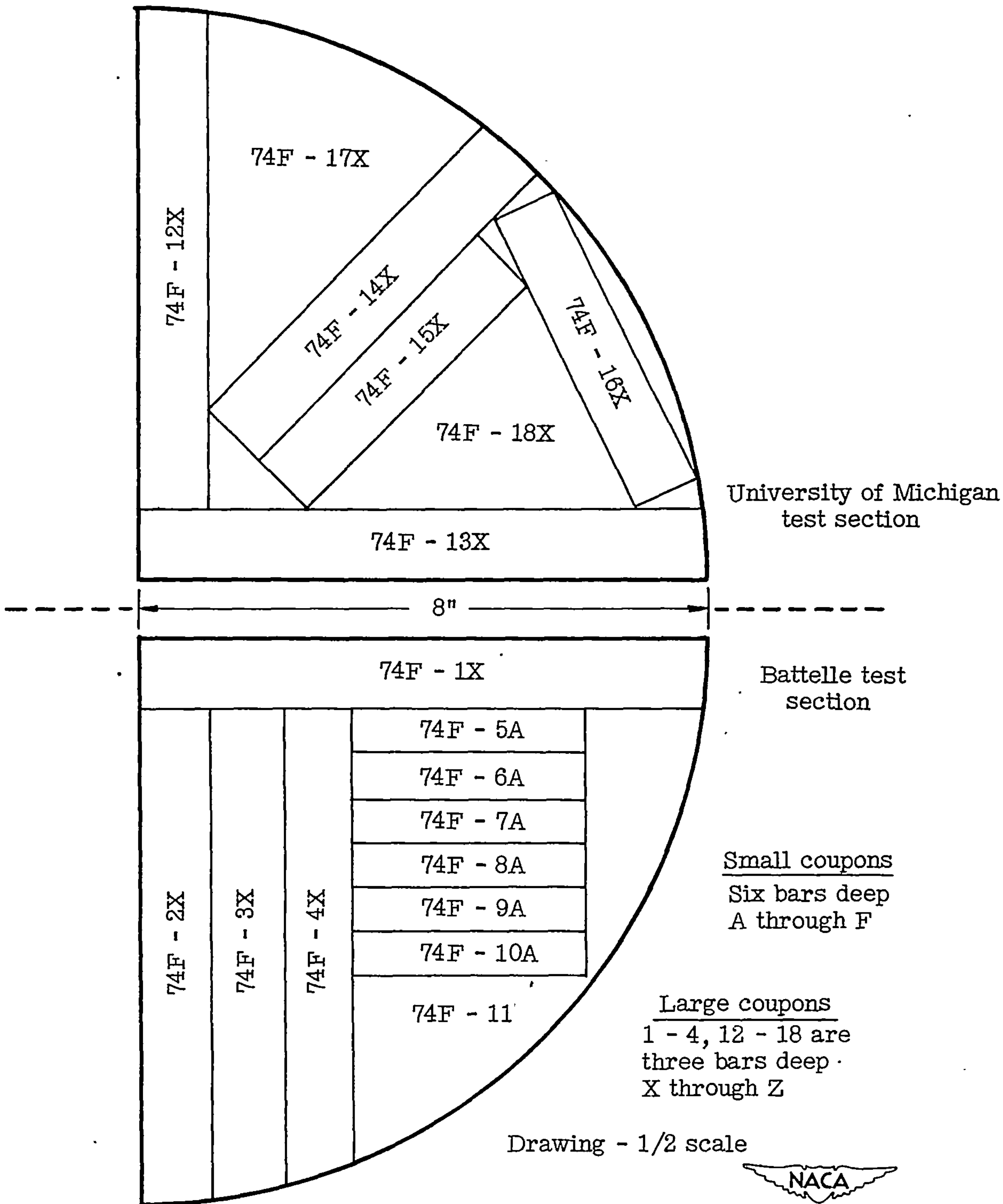
NR-74B-QA Heat-treated and aged disc; 2300° F, $3\frac{1}{4}$ hr; water-quenched plus 16 hr at 1400° F; air-cool.

NR-76B-F As-forged and aged disc; 16 hr at 1400° F; air-cool.

NR-76B-Q Heat-treated and aged disc; 2300° F, $2\frac{1}{2}$ hr; water-quenched plus 16 hr at 1400° F; air-cool.

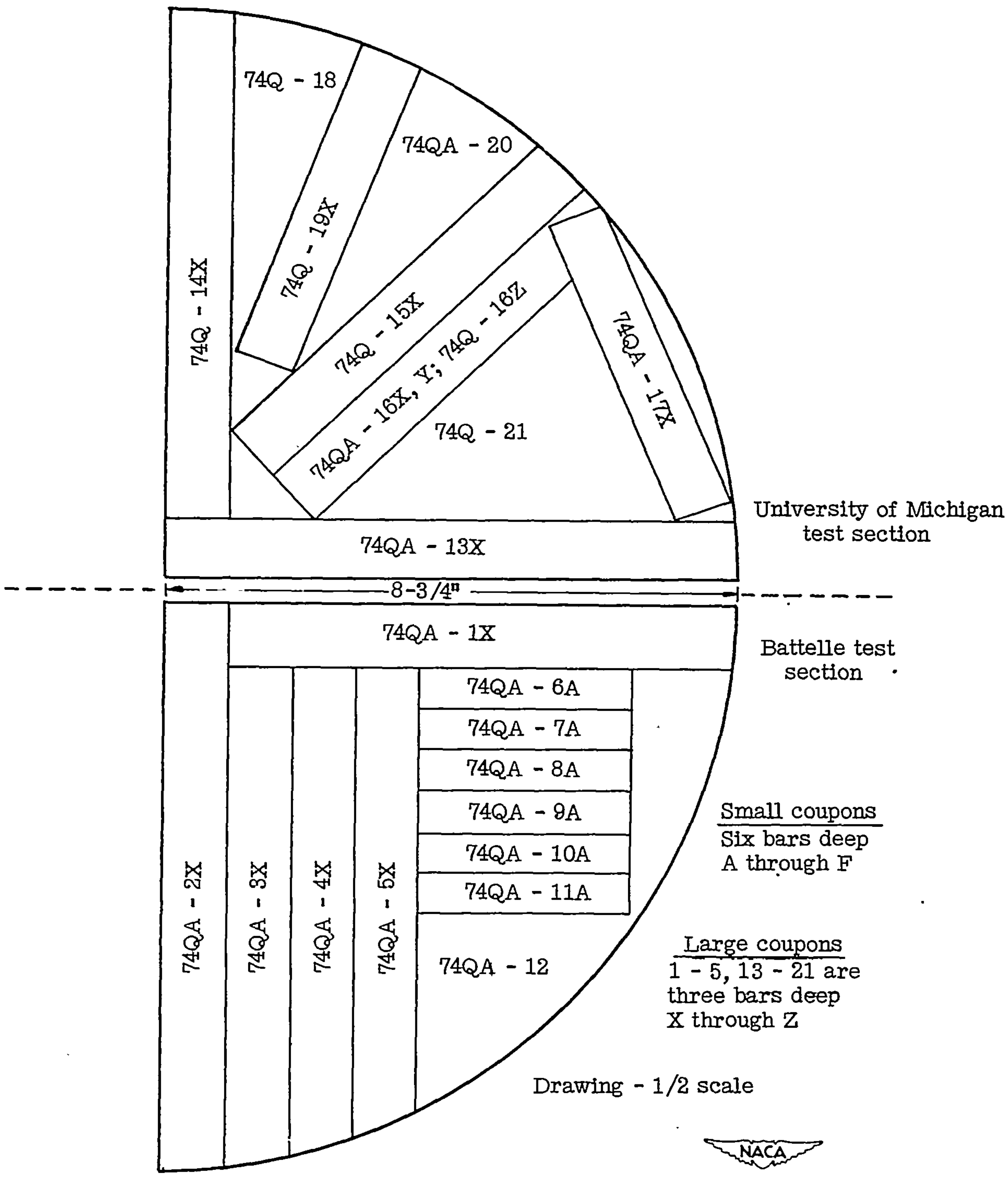
[b]S-816 disc data taken from reference 10.

[c]Estimated values.



Disc dimensions: 18-inch diameter, $3\frac{3}{8}$ inches thick

Figure 1.- Location of test coupons in forged and aged S-590 alloy disc NR-74B-F. Coupons: as-forged; 16 hours at 1400° F.



Disc dimensions: 18-inch diameter, 3 inches thick

Figure 2.- Location of test coupons in heat-treated S-590 alloy disc NR-74B-Q. Coupons 74Q: 2300° F, water-quenched. Coupons 74QA: 2300° F, water-quenched; 16 hours at 1400° F.

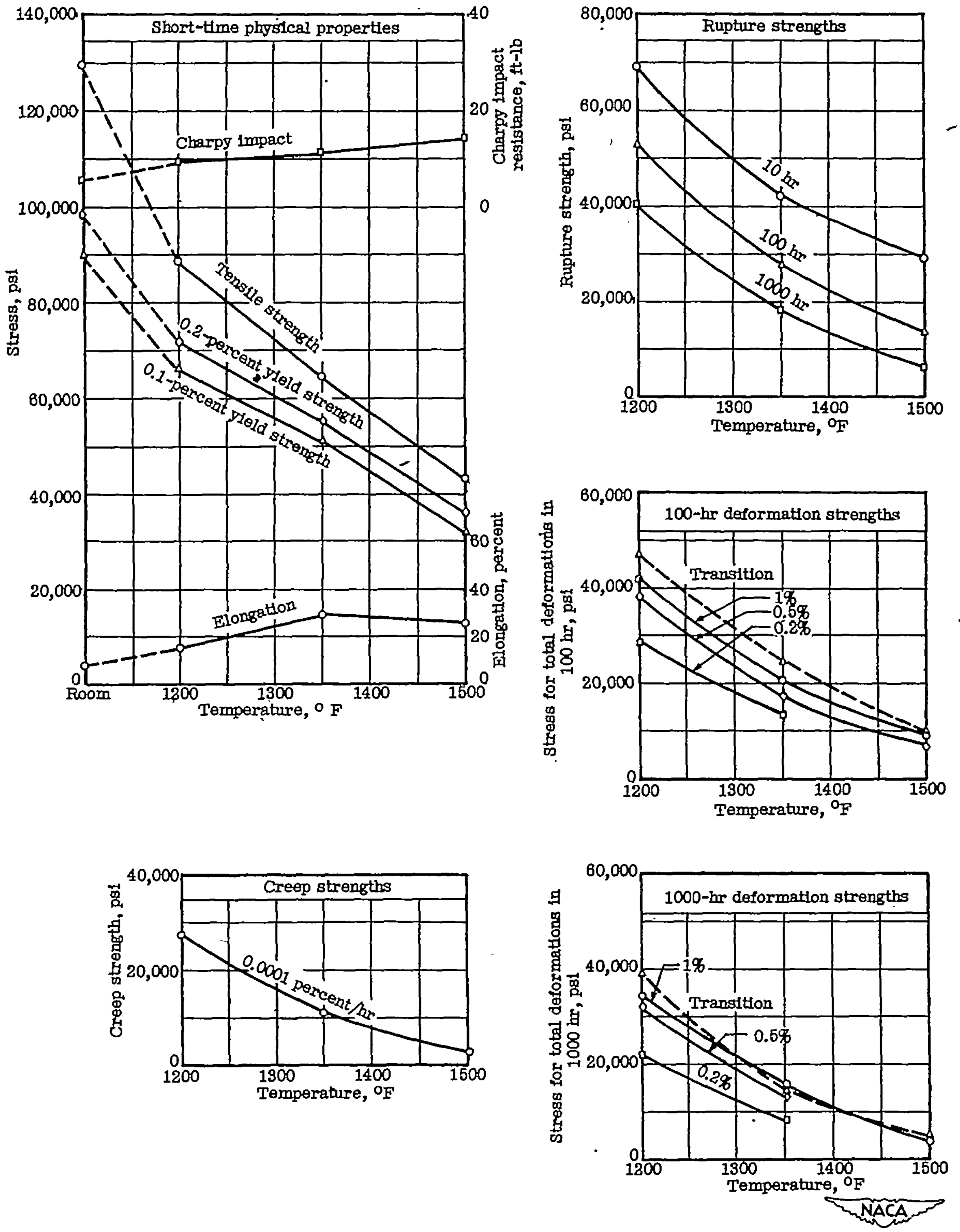


Figure 3.- Summary of properties of S-590 alloy disc NR-74B-F. Disc treatment: as-forged; 16 hours at 1400° F.

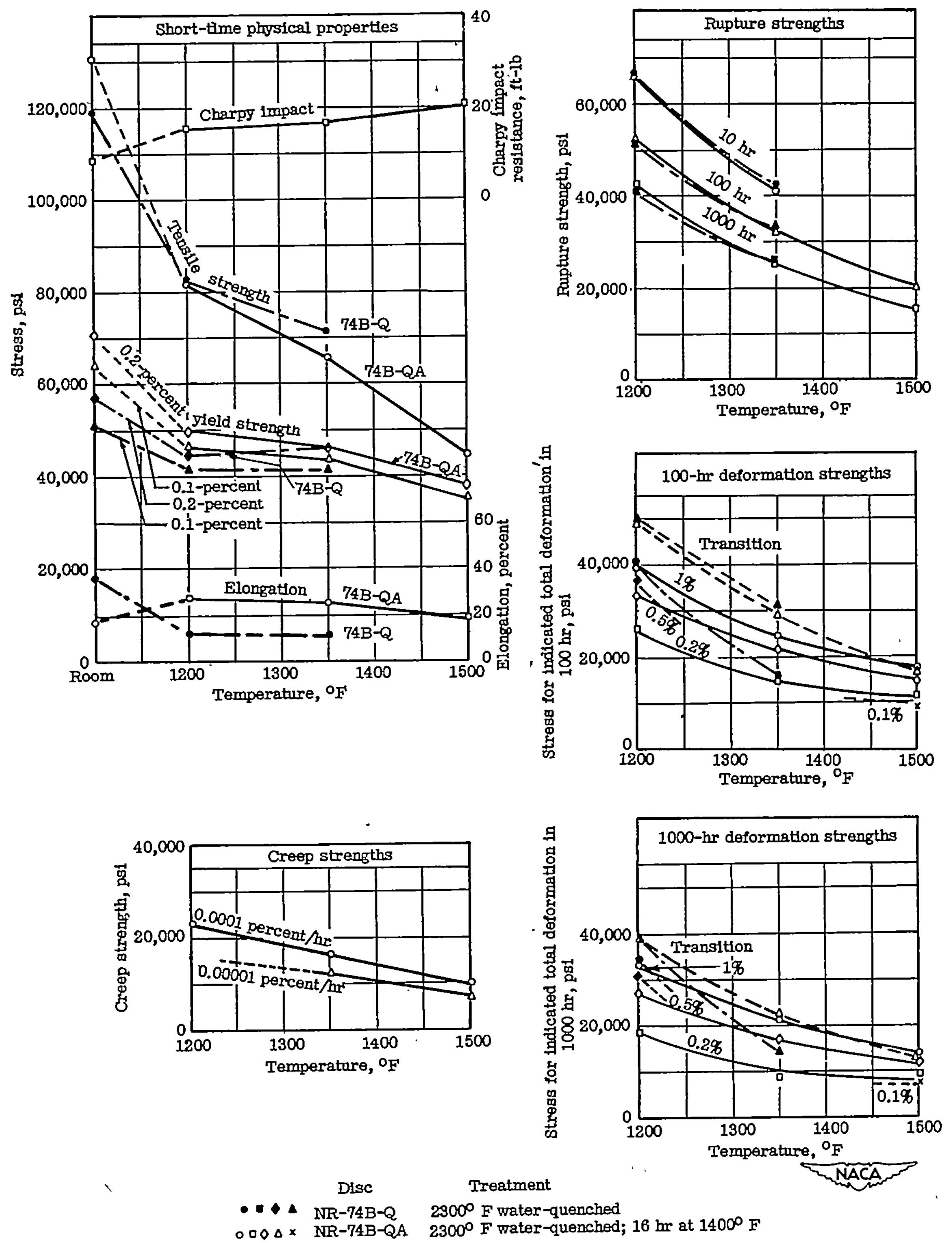


Figure 4.- Summary of properties of S-590 alloy discs NR-74B-Q and NR-74B-QA.

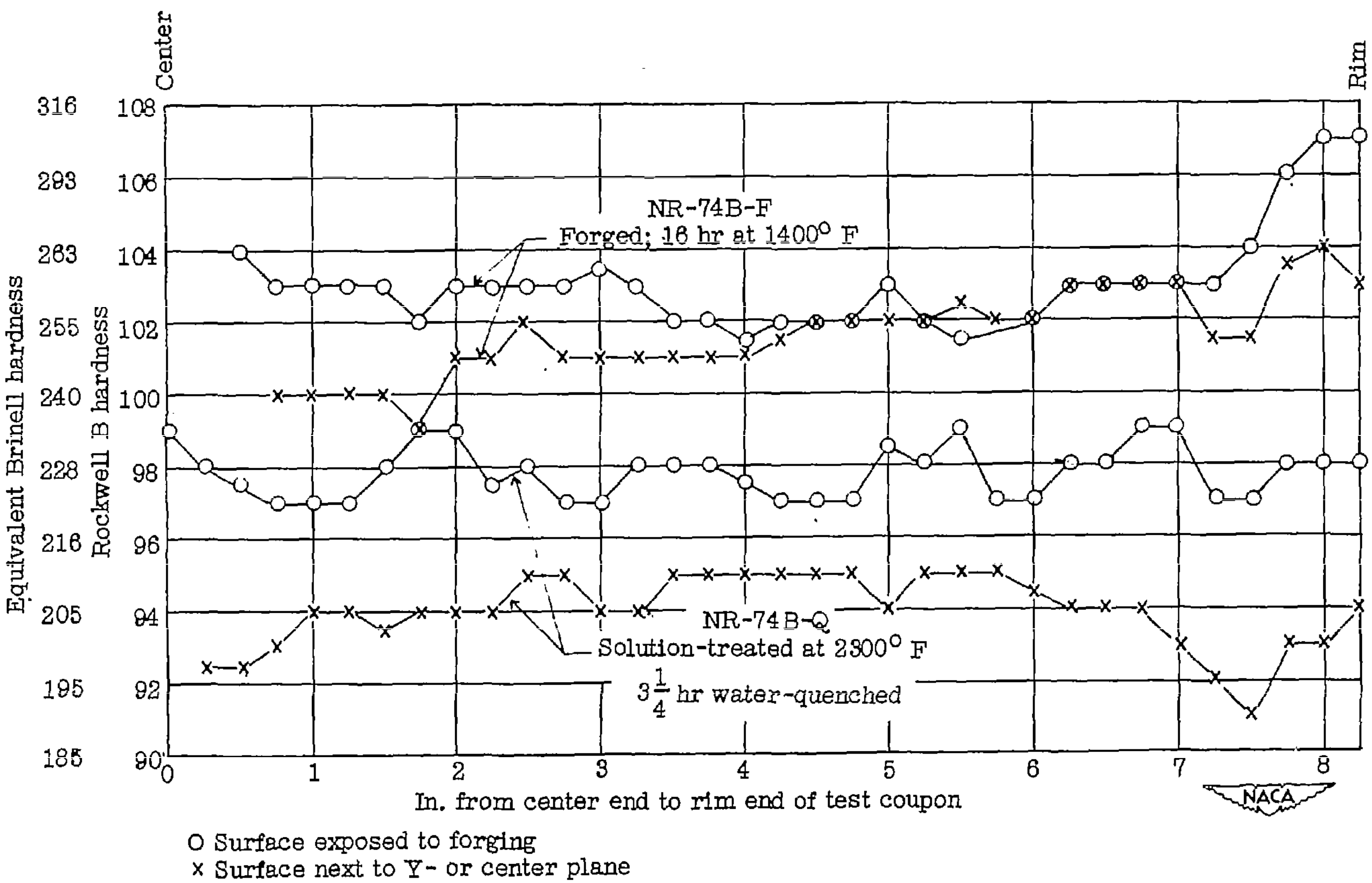
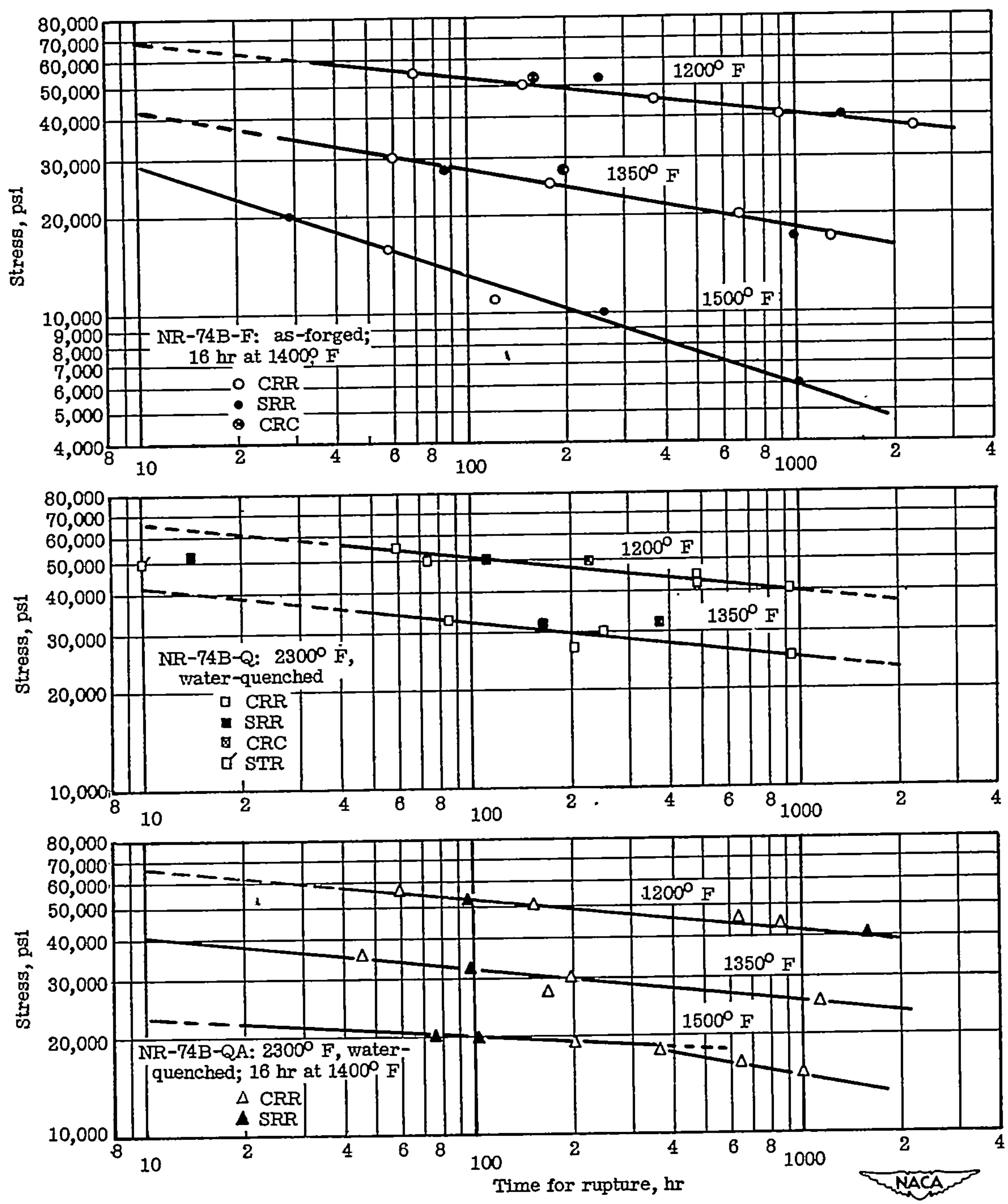


Figure 5.- Variation in hardness from center to rim of S-590 alloy discs NR-74B.



Specimen location

CRR Center-plane radial specimen near rim
SRR Surface-plane radial specimen near rim
CRC Center-plane radial specimen near center
STR Surface-plane tangential specimen near rim

Figure 6:- Curves of stress against rupture time at 1200°, 1350°, and 1500° F for S-590 alloy discs NR-74B.

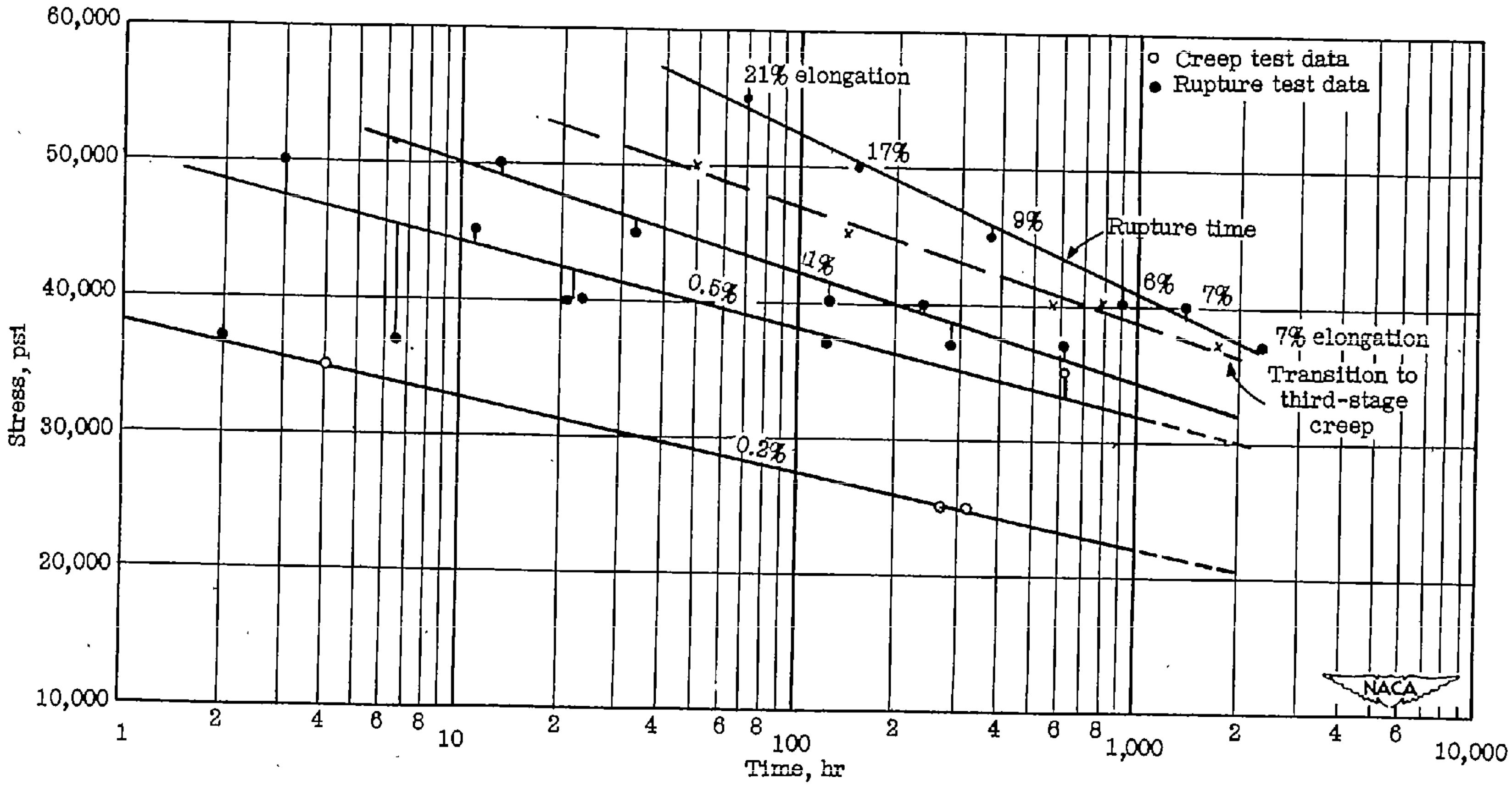


Figure 7.- Curves of stress against time for total deformation at 1200° F for S-590 alloy disc NR-74B-F. Heat treatment: as-forged; 16 hours at 1400° F.

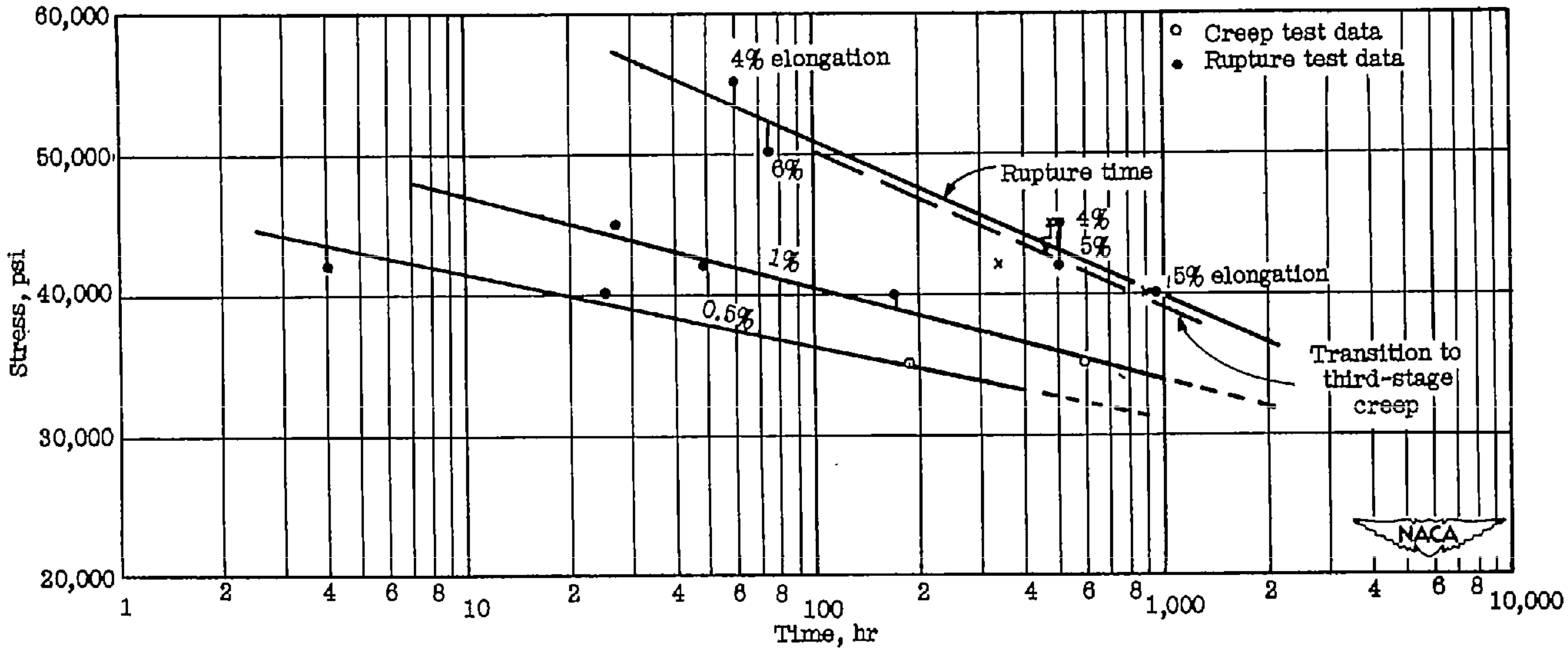


Figure 8.- Curves of stress against time for total deformation at 1200° F for S-590 alloy disc NR-74B-Q. Heat treatment: 2300° F water-quenched.

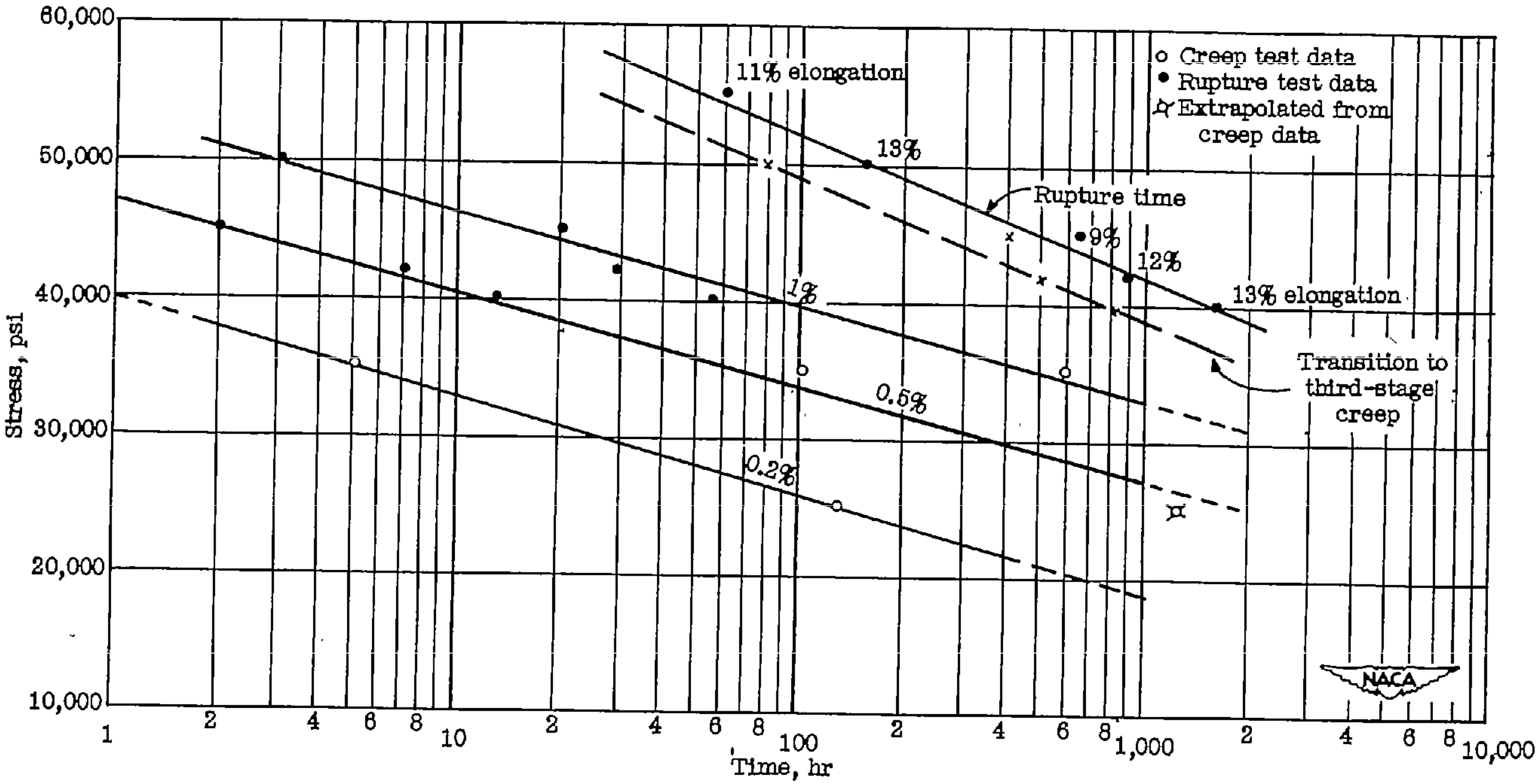


Figure 9.- Curves of stress against time for total deformation at 1200° F for S-590 alloy disc NR-74B-QA. Heat treatment: 2300° F water-quenched; 16 hours at 1400° F.

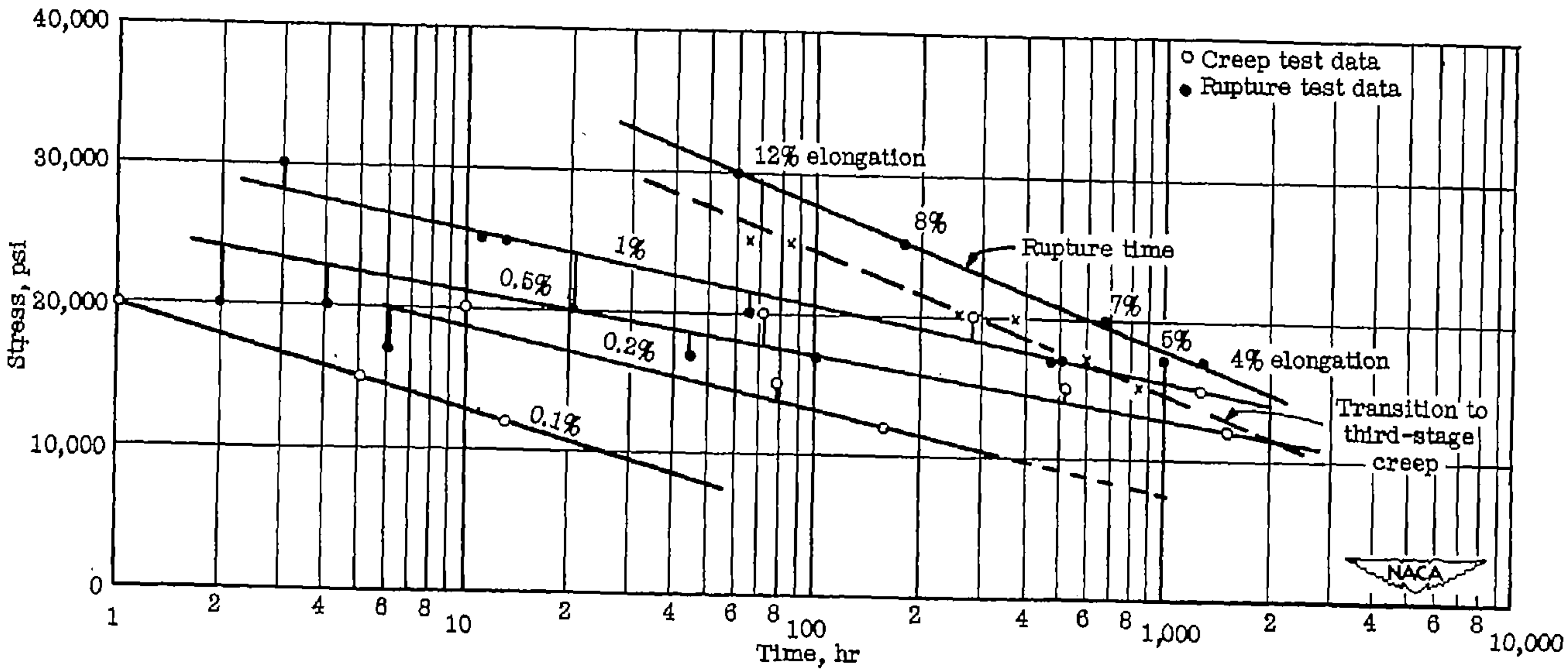


Figure 10.- Curves of stress against time for total deformation at 1350° F for S-590 alloy disc NR-74B-F. Heat treatment: as-forged; 16 hours at 1400° F.

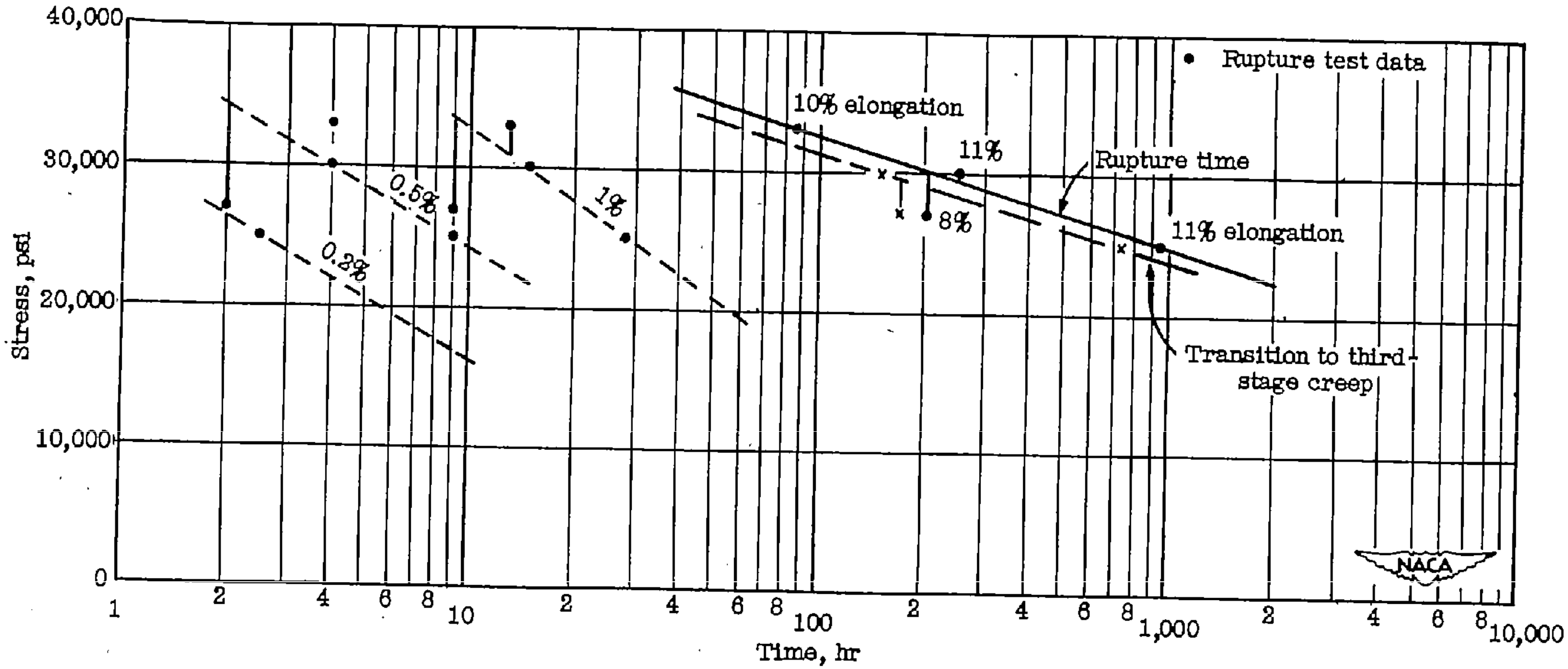


Figure 11.- Curves of stress against time for total deformation at 1350° F for S-590 alloy disc NR-74B-Q. Heat treatment: 2300° F water-quenched.

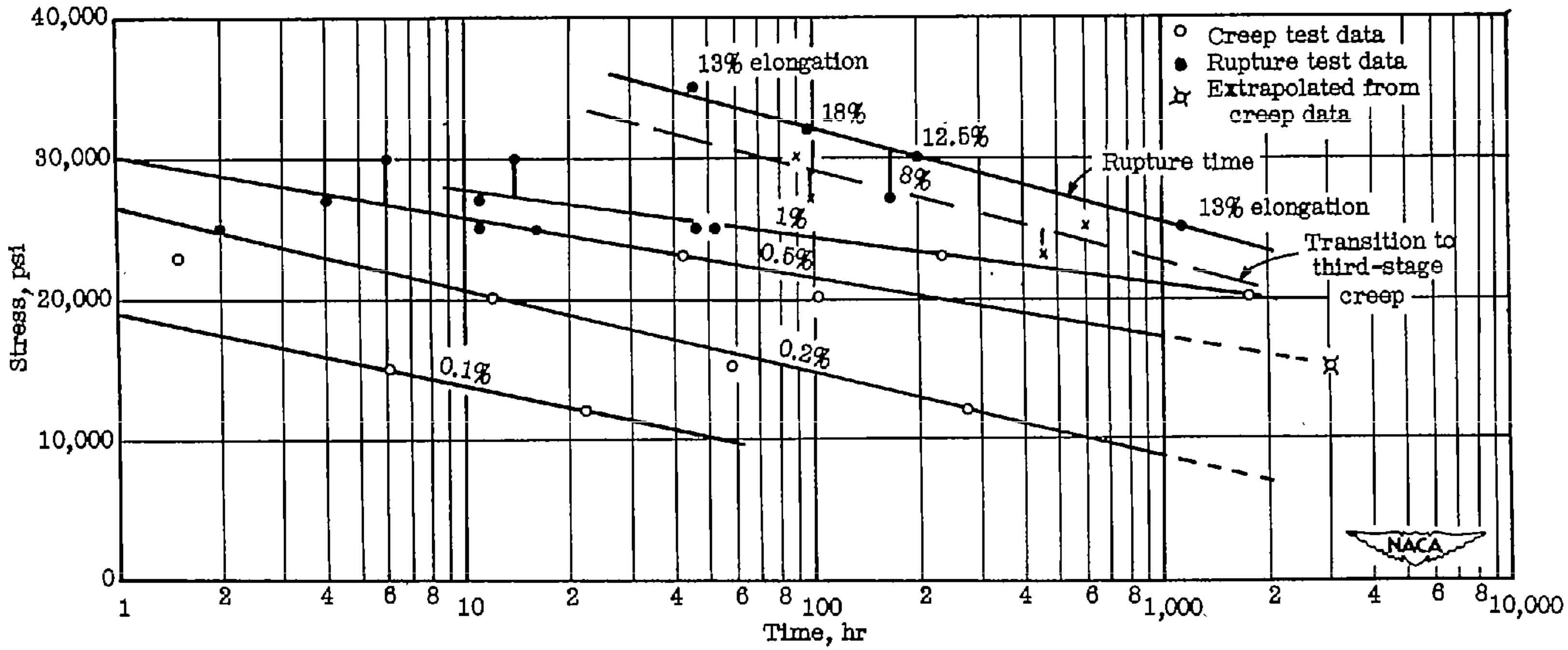


Figure 12.- Curves of stress against time for total deformation at 1350° F for S-590 alloy disc NR-74B-QA. Heat treatment: 2300° F water-quenched; 16 hours at 1400° F.

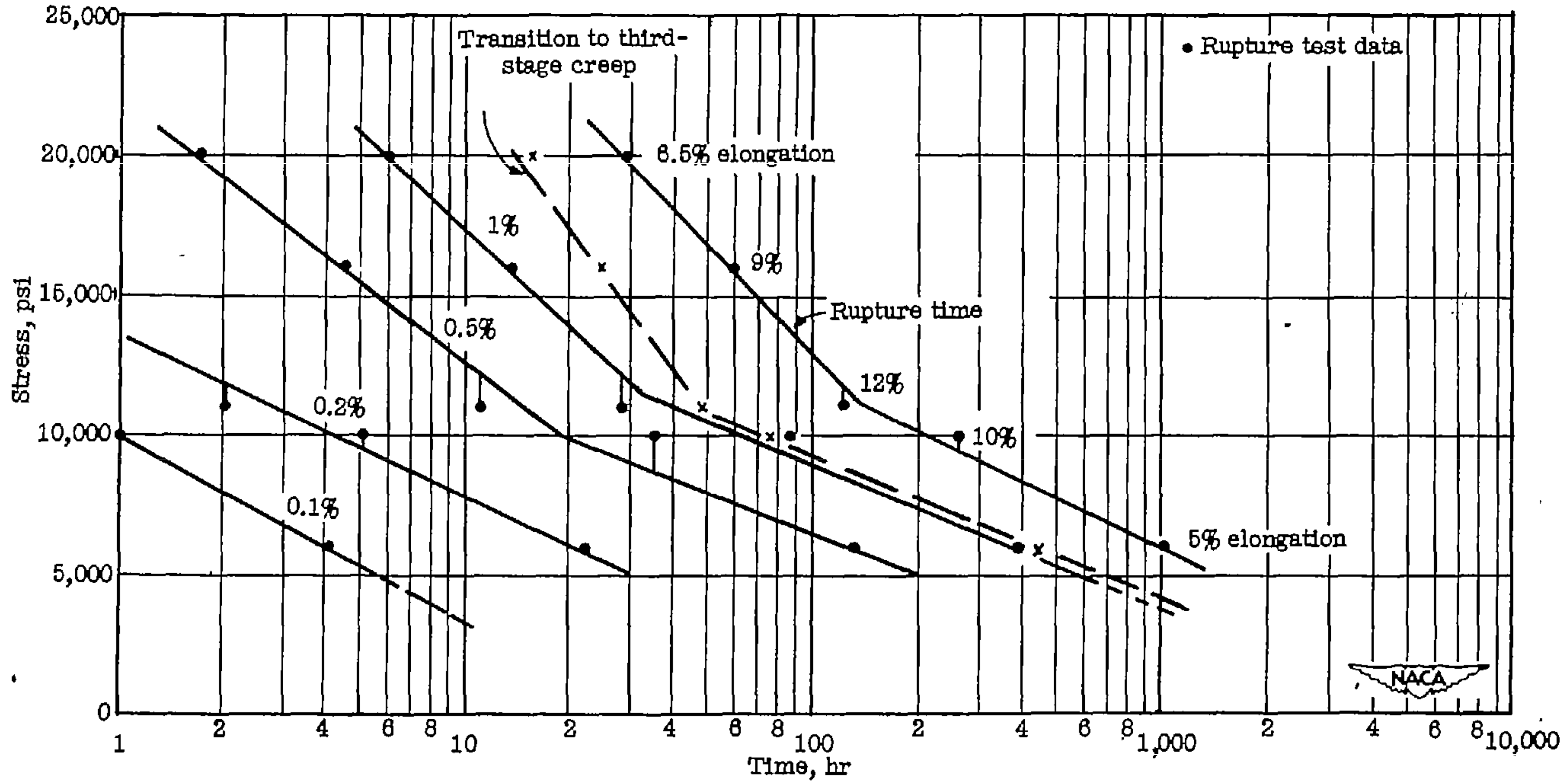


Figure 13.- Curves of stress against time for total deformation at 1500° F for S-590 alloy disc NR-74B-F. Heat treatment: as-forged; 16 hours at 1400° F.

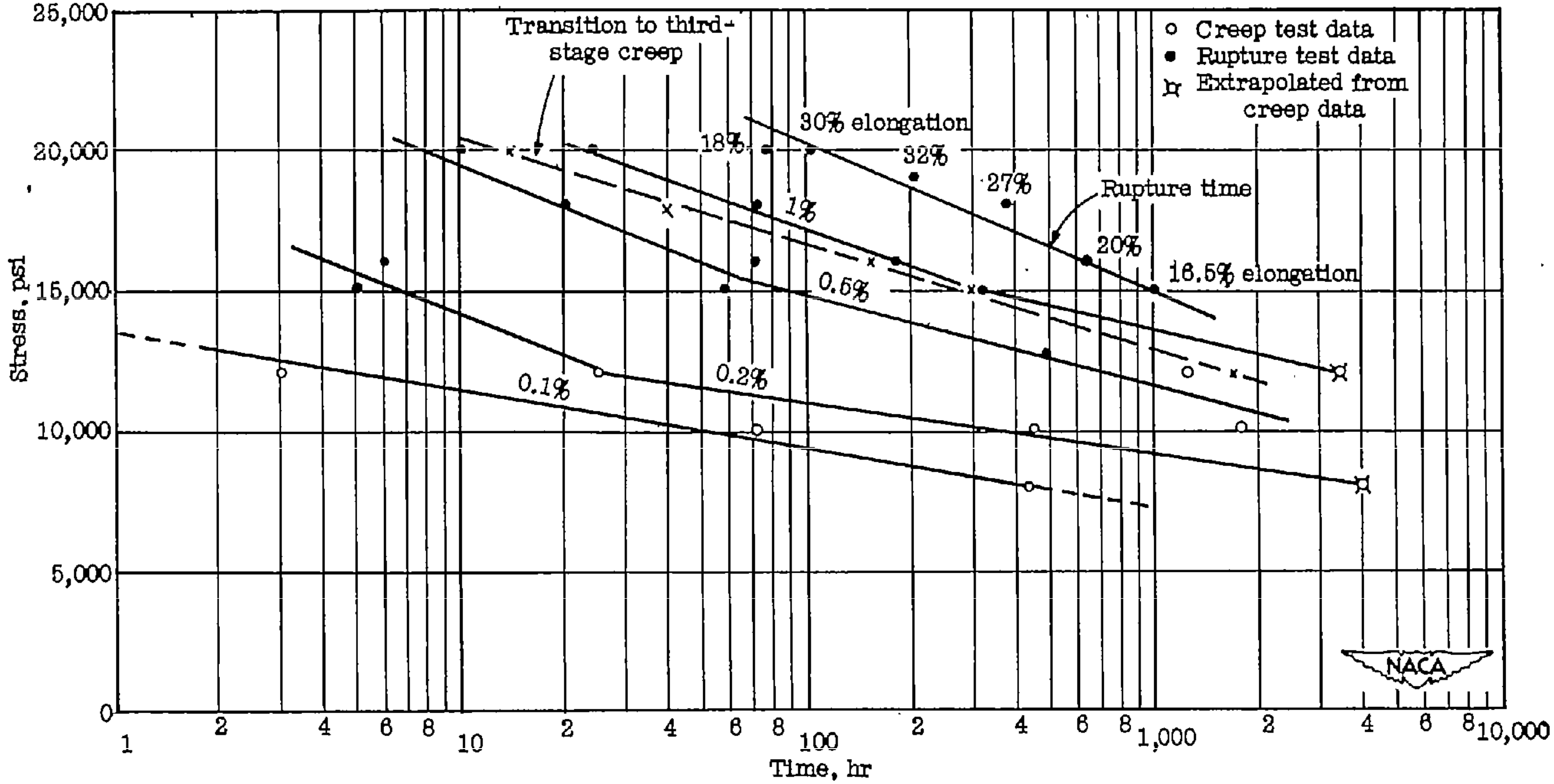


Figure 14.- Curves of stress against time for total deformation at 1500° F for S-590 alloy disc NR-74B-QA. Heat treatment: 2300° F water-quenched; 16 hours at 1400° F.

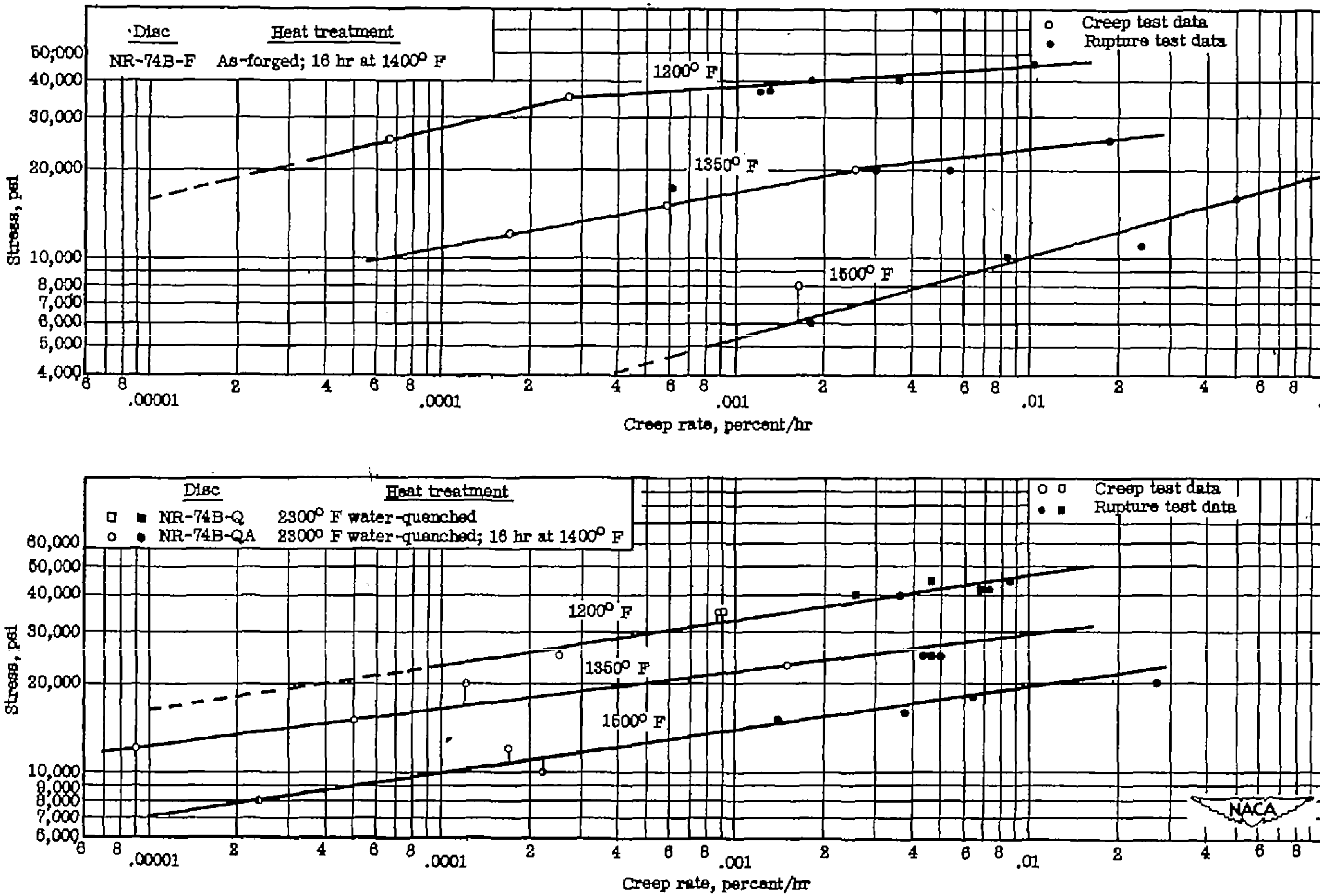
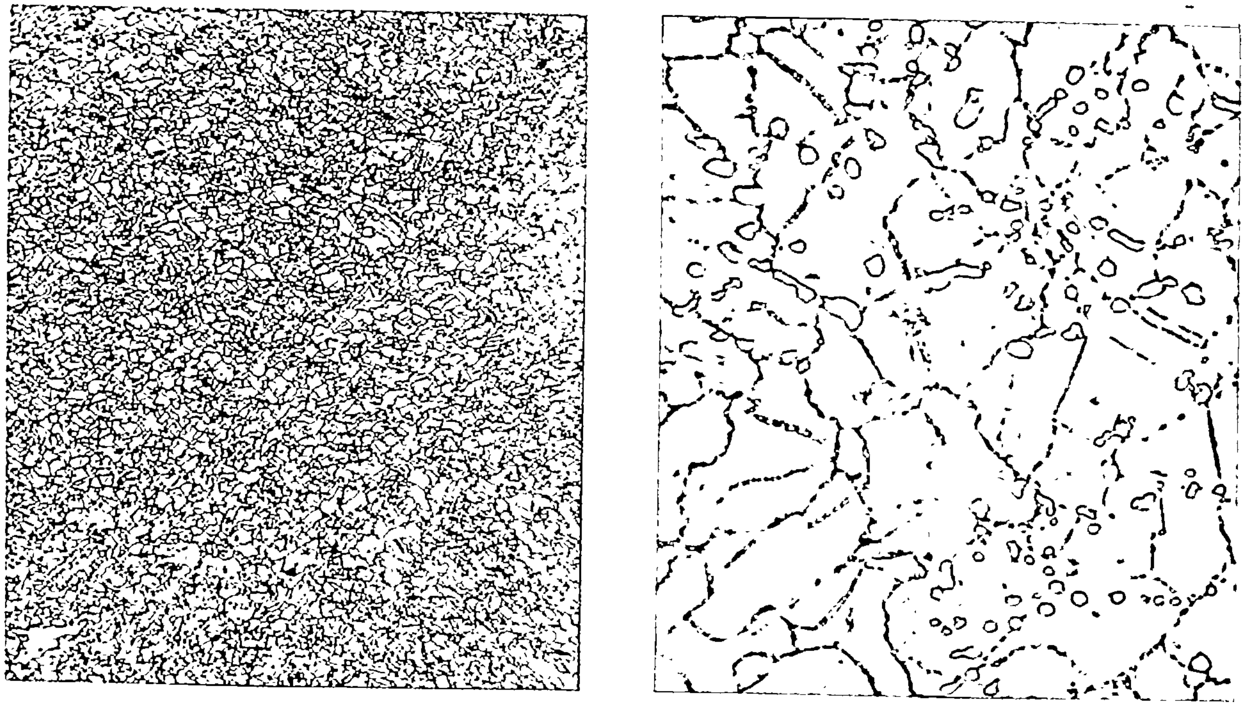
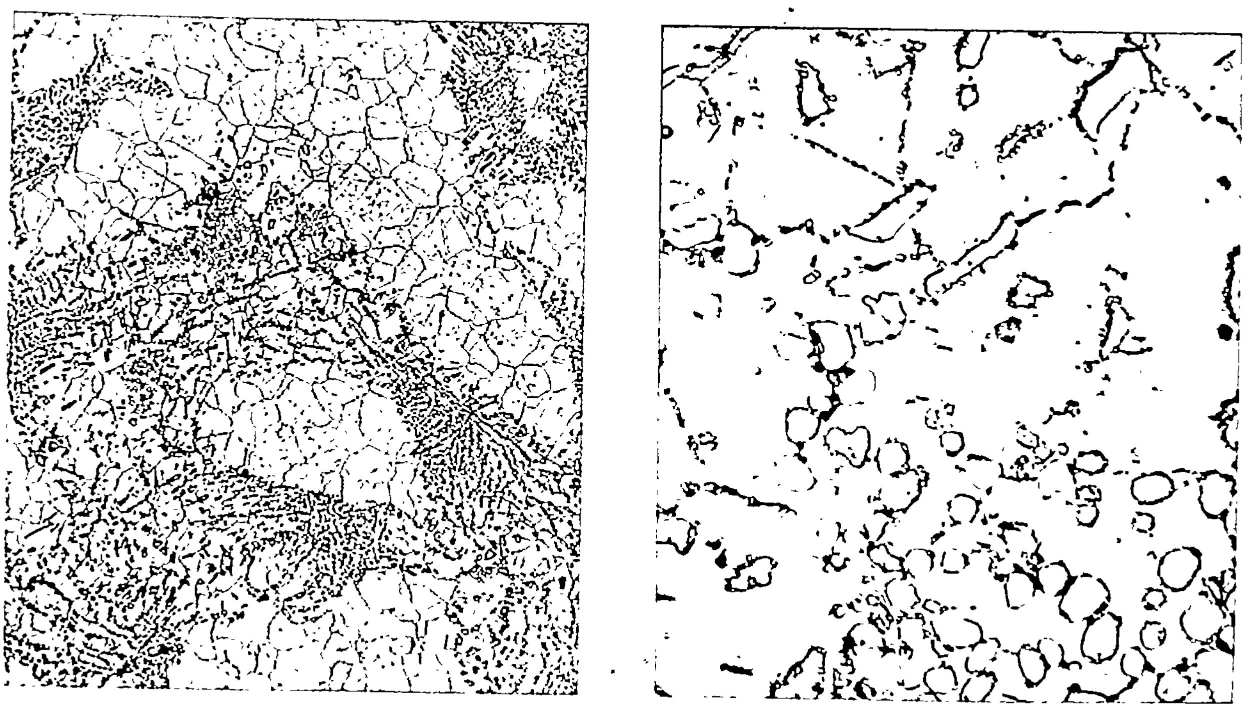


Figure 15.- Curves of stress against creep rate at 1200°, 1350°, and 1500° F for S-590 alloy discs NR-74B.



100X 1000X

(a) Radial section near rim of disc in center plane.



100X 1000X

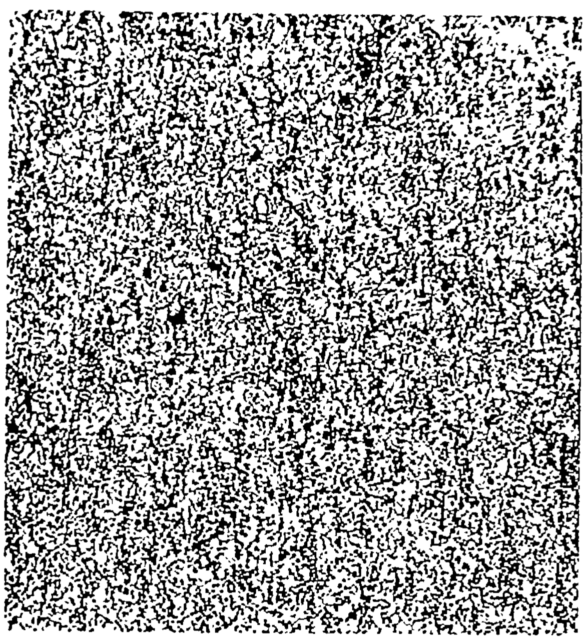
(b) Radial section near center of disc in center plane.

Figure 16.- Original microstructure of S-590 alloy disc NR-74B-F. Electrolytic chromic acid etch. Disc treatment: as-forged; 16 hours at 1400° F.

100X

1000X

(a) Specimen 13X; 1002 hours at 1200° F under 35,000 psi.

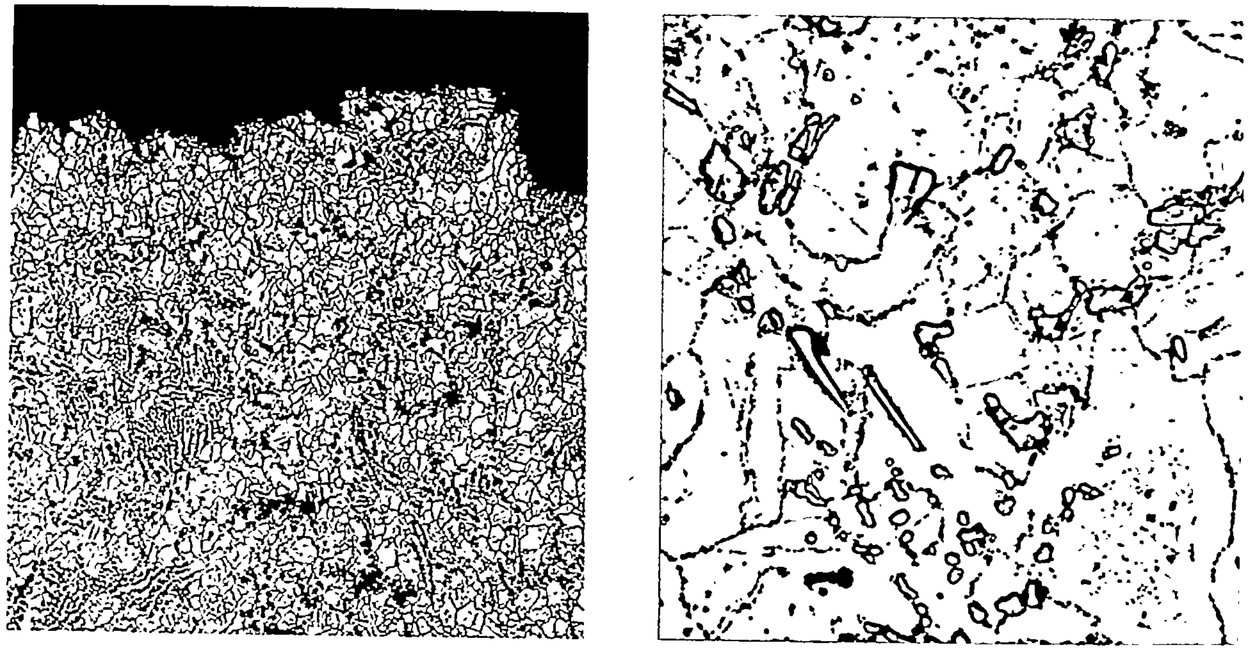


100X

1000X

(b) Specimen 2X; 1872 hours at 1350° F under 15,000 psi.

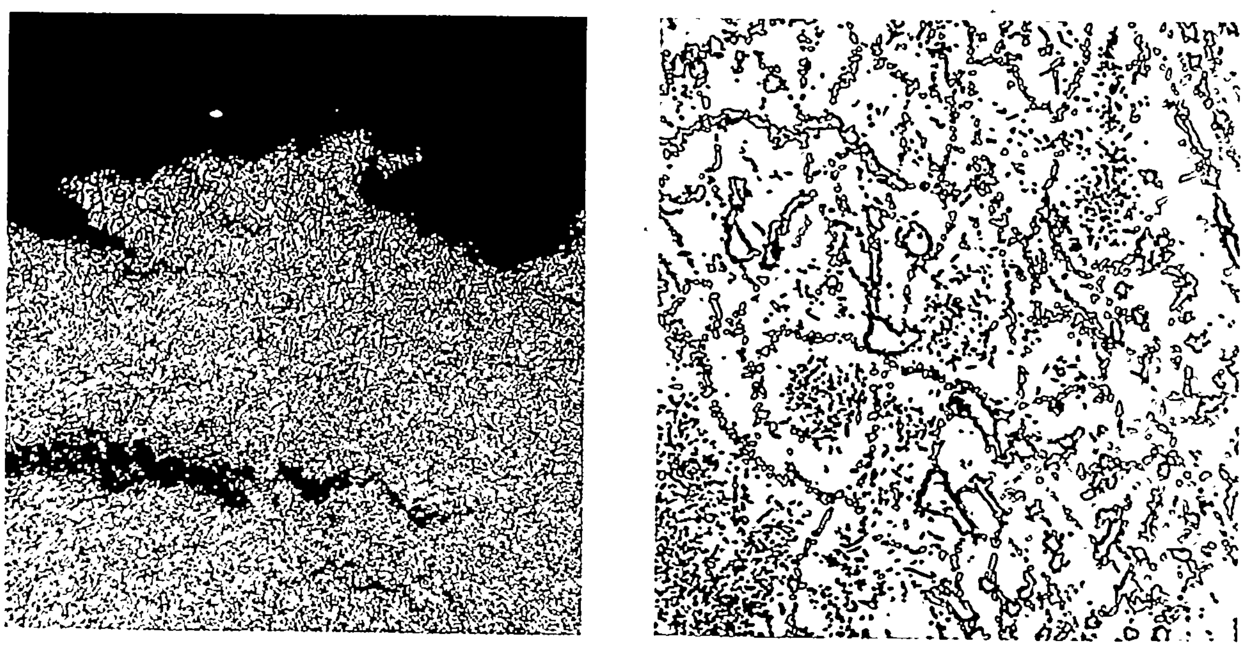
Figure 17.- Microstructure of specimens from S-590 alloy disc NR-74B-F after creep tests. Electrolytic chromic acid etch. Disc treatment: as-forged; 16 hours at 1400° F.



Fracture - 100X

Interior - 1000X

(a) Specimen 12Y; 2310 hours for rupture at 1200° F under 37,000 psi.

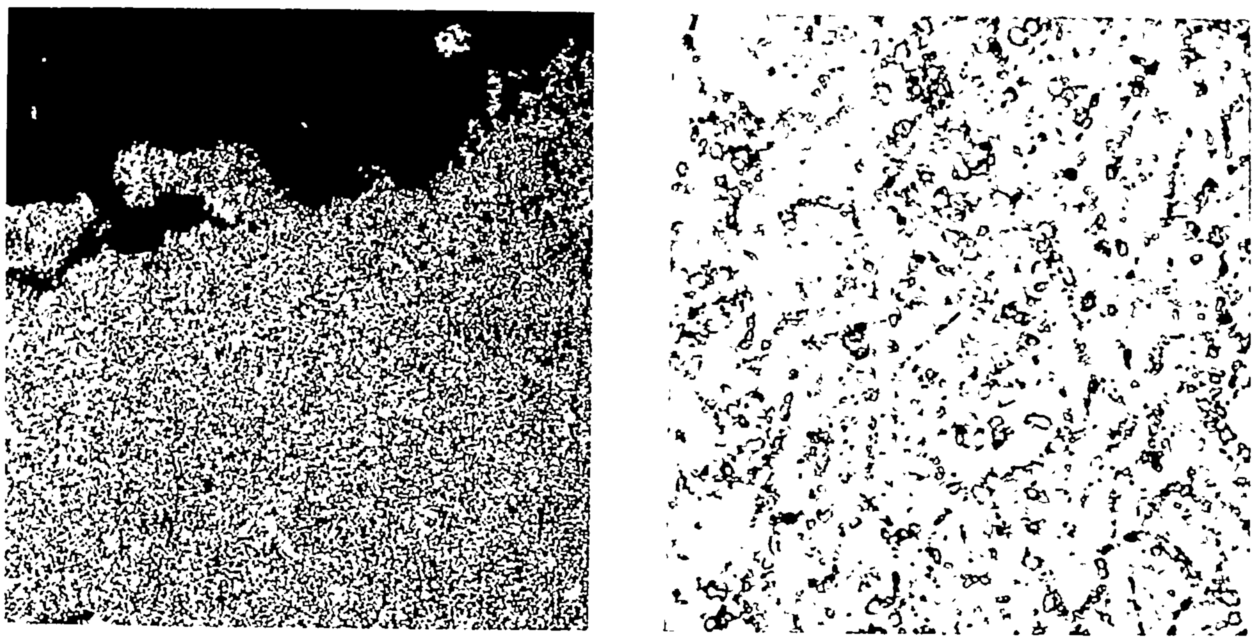


Fracture - 100X

Interior - 1000X

(b) Specimen 12Y; 1291 hours for rupture at 1350° F under 17,000 psi.

Figure 18.- Microstructure of specimens from S-590 alloy disc NR-74B-F after stress-rupture tests. Electrolytic chromic acid etch. Disc treatment: as-forged; 16 hours at 1400° F.

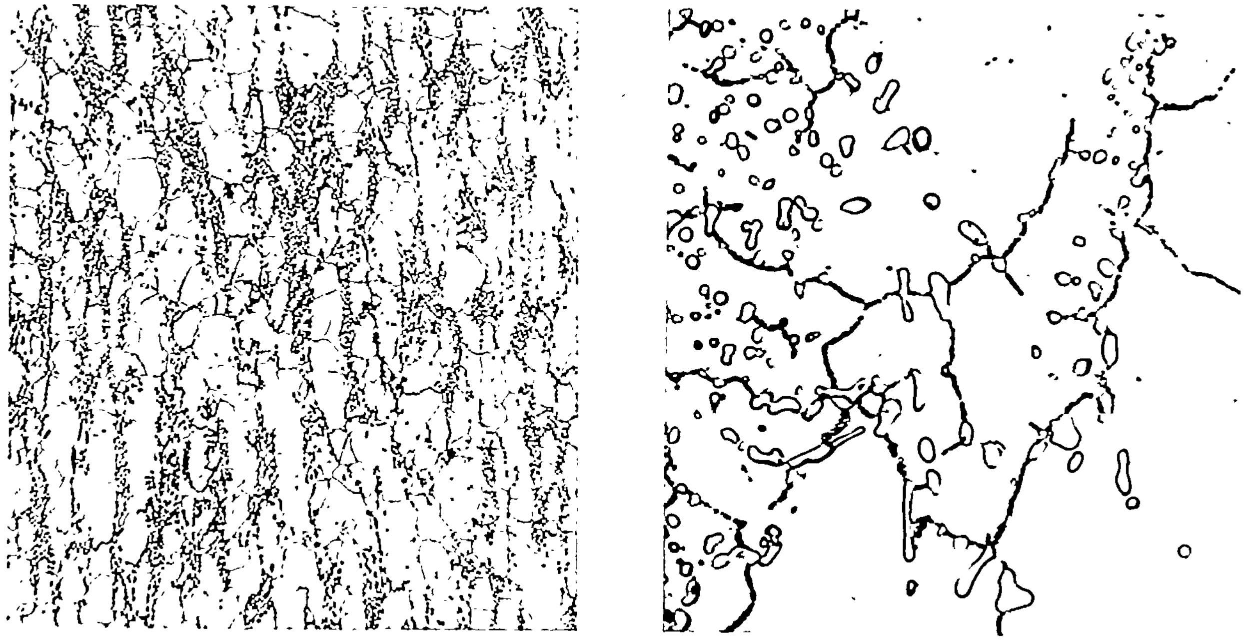


Fracture - 100X

Interior - 1000X

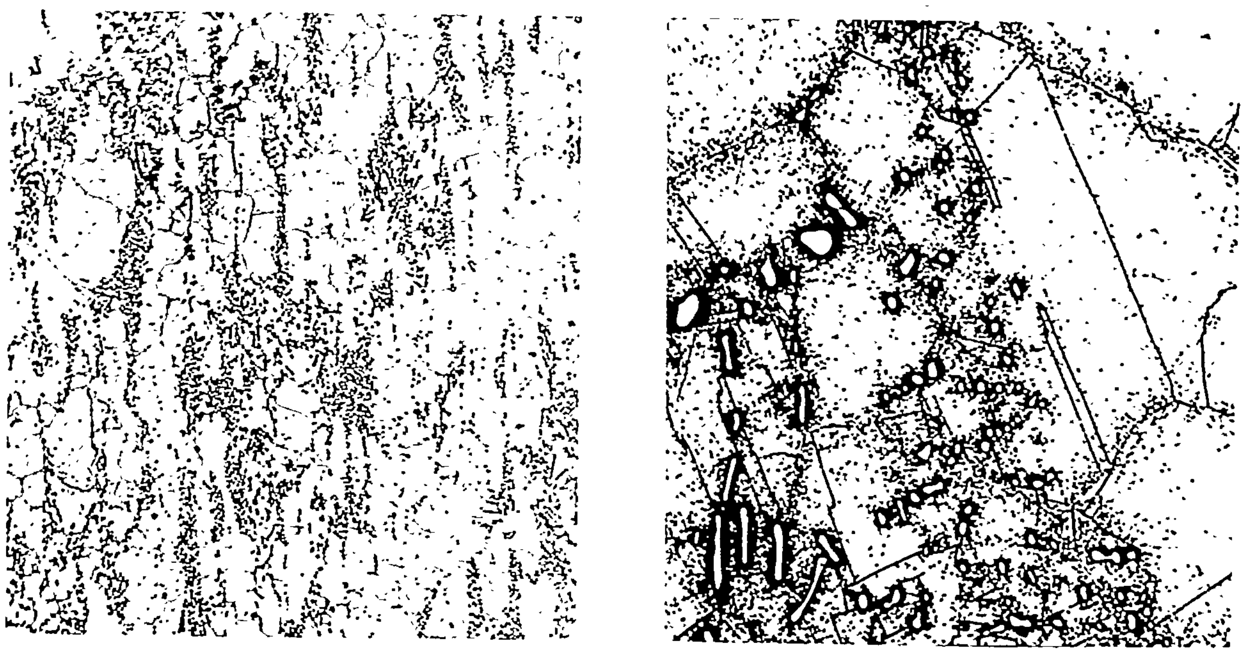
(c) Specimen 9F; 1018 hours for rupture at 1500° F under 6000 psi.

Figure 18.- Concluded.



100X 1000X

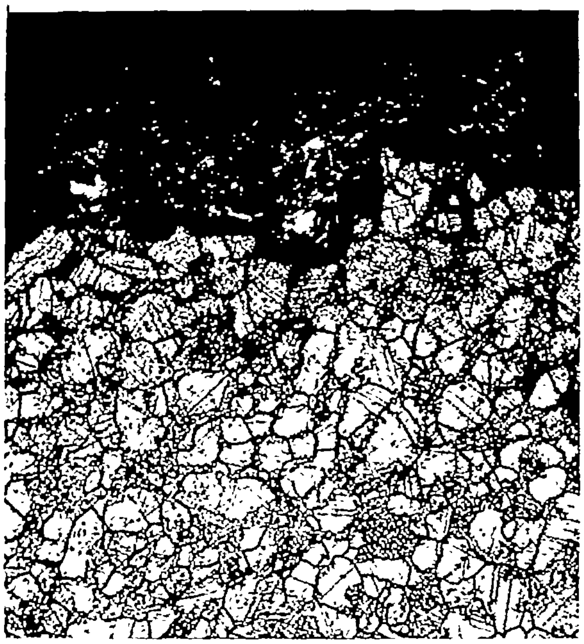
(a) Disc NR-74B-Q; radial section near rim of disc in center plane. Electrolytic chromic acid etch. Disc treatment: 2300° F water-quenched.



100X 1000X

(b) Disc NR-74B-QA; radial section near rim of disc in center plane. Electrolytic sodium cyanide etch. Disc treatment: 2300° F water-quenched; 16 hours at 1400° F.

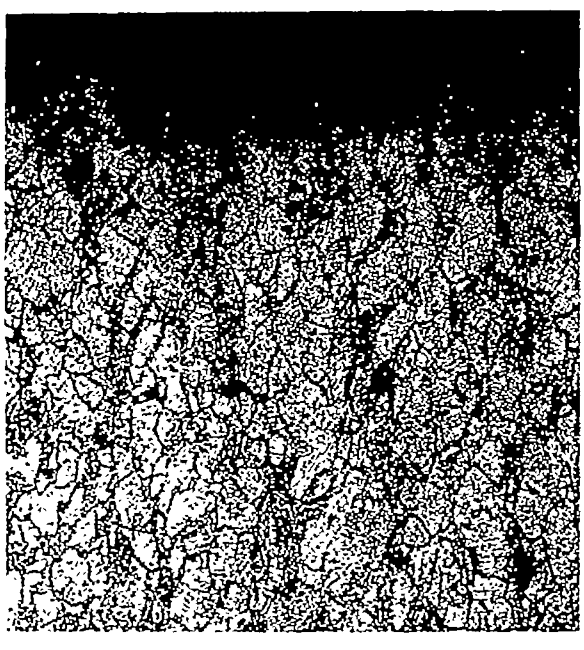
Figure 19.- Original microstructure of S-590 alloy discs NR-74B-Q and NR-74B-QA.



Fracture - 100X

Interior - 1000X

(a) Specimen 18Y; 937 hours for rupture at 1200° F under 40,000 psi.

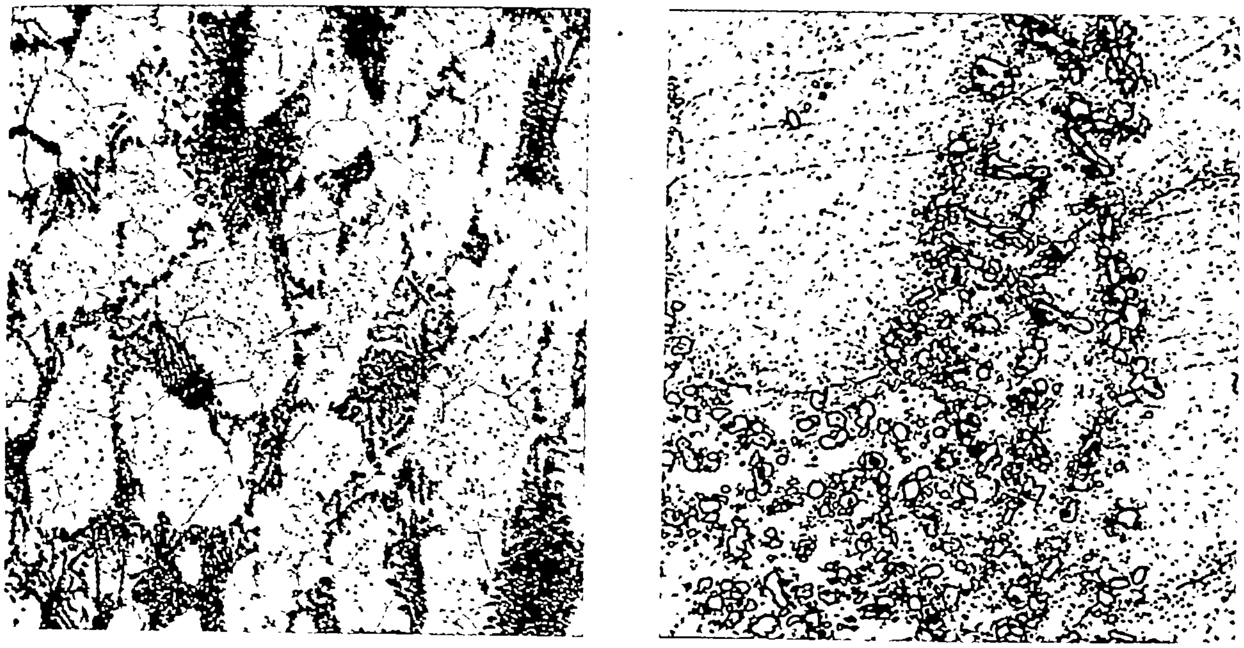


Fracture - 100X

Interior - 1000X

(b) Specimen 14Y; 951 hours for rupture at 1350° F under 25,000 psi.

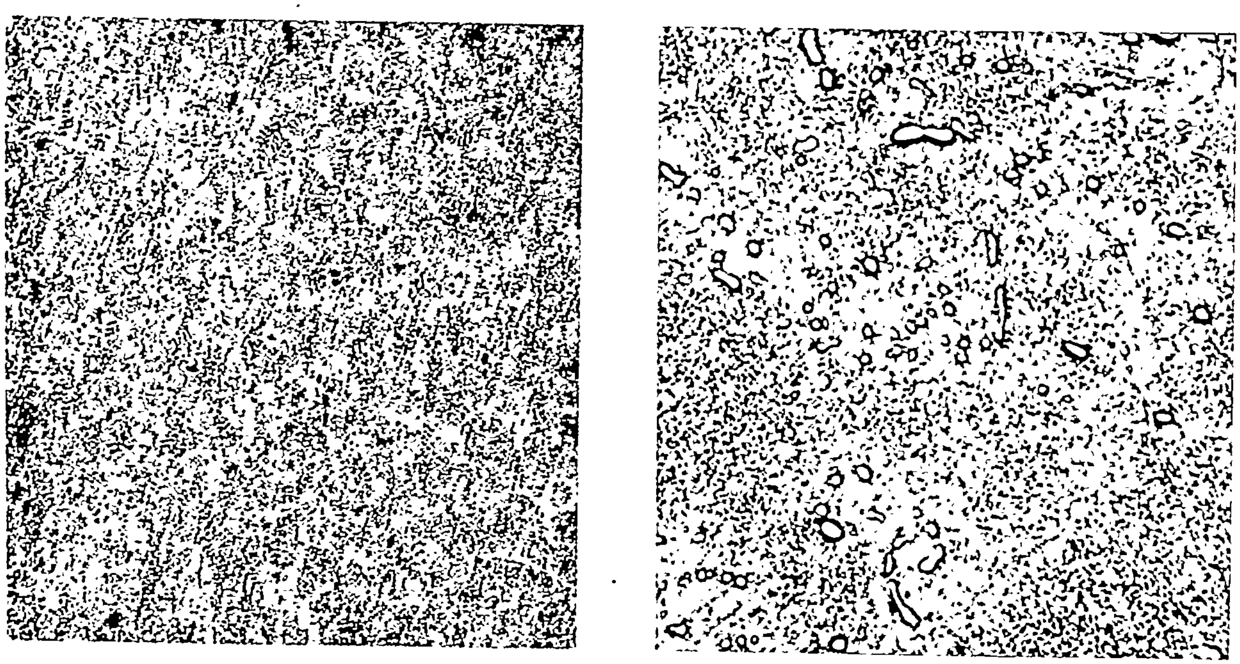
Figure 20.- Microstructure of specimens from S-590 alloy disc NR-74B-Q after stress-rupture tests. Electrolytic sodium cyanide etch. Disc treatment: 2300° F water-quenched.



100X

1000X

(a) Specimen 13Z; 1002 hours at 1200° F under 35,000 psi.



100X

1000X

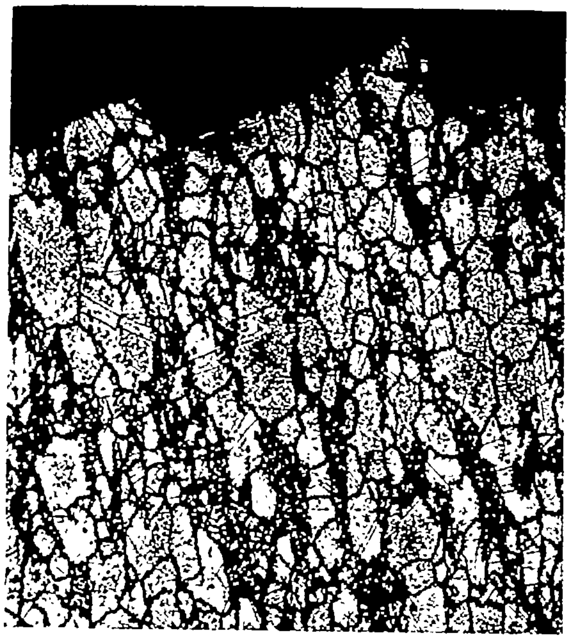
(b) Specimen 1X; 2282 hours at 1350° F under 15,000 psi.

Figure 21.- Microstructure of specimens from S-590 alloy disc NR-74B-QA after creep tests. Electrolytic chromic acid etch. Disc treatment: 2300° F water-quenched; 16 hours at 1400° F.

100X 1000X

(c) Specimen 4X; 2136 hours at 1500° F under 12,000 psi.

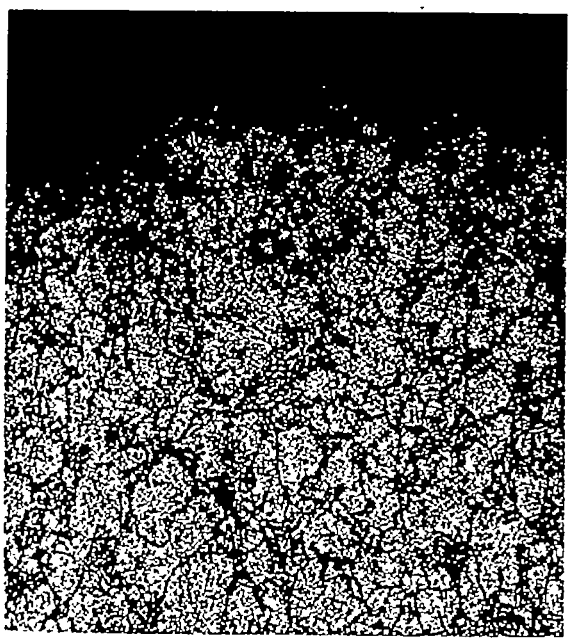
Figure 21.- Concluded.



Fracture - 100X

Interior - 1000X

(a) Specimen 13X; 1596 hours for rupture at 1200° F under 40,000 psi.

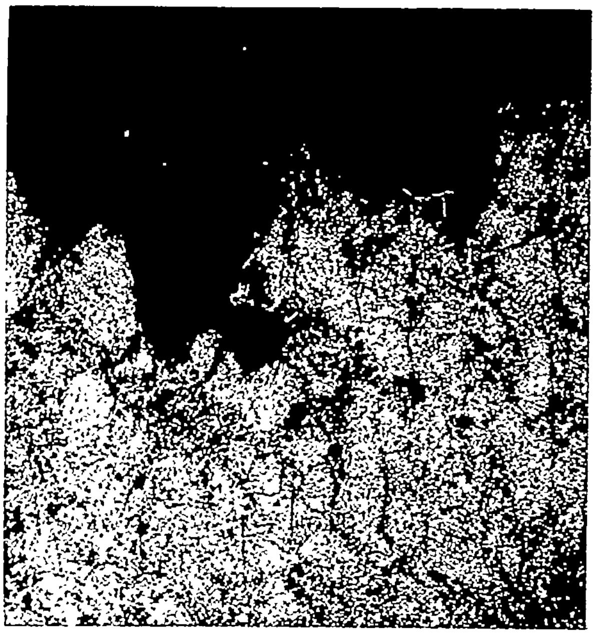


Fracture - 100X

Interior - 1000X

(b) Specimen 13Y; 1121 hours for rupture at 1350° F under 25,000 psi.

Figure 22.- Microstructure of specimens from S-590 alloy disc NR-74B-QA after stress-rupture tests. Electrolytic chromic acid etch. Disc treatment: 2300° F water-quenched; 16 hours at 1400° F.



Fracture - 100X

Interior - 1000X

(c) Specimen 11D; 1000 hours for rupture at 1500° F under 15,000 psi.

Figure 22.- Concluded.

TABLE VII

DATA ON STRESS AND TIME FOR TOTAL DEFORMATION AT 1500° F FOR S-590 ALLOY DISCS NR-74B

[NDRC and Navy data]

Disc (a)	Specimen number	Stress (psi)	Initial deformation (percent)	Time (hr) for total deformations of–						Transition to third-stage creep	
				0.1 percent	0.2 percent	0.5 percent	1 percent	2 percent	5 percent	Time (hr)	Deformation (percent)
NR-74B-F	9A	20,000	-----	---	-----	1.7	6	16	28	15.5	1.95
	9D	16,000	-----	---	-----	4.5	13.5	31	54	24	1.56
	9E	11,000	-----	---	2	11	28	64	101	48	1.42
	2Z	10,000	0.069	1	5	35	86	145	250	74	0.92
	9F	6,000	-----	4	22	132	392	700	---	464	1.17
NR-74B-QA	11F	20,000	-----	---	-----	10	24	42	69	14	.60
	11C	18,000	-----	---	-----	20	72	119	220	40	.62
	11B	16,000	-----	---	6	70	180	306	474	155	.85
	11D	15,000	-----	---	5	58	325	545	787	300	.94
	4X	12,000	.077	3	25	1270	[b]3400	---	---	1700	.58
	1Z	10,000	.068	72	456	1800	-------	---	---	------	----
	2X	8,000	.036	430	[b]4000	------	-------	---	---	------	----

[a]Heat treatments:
NR-74B-F As-forged; 16 hr at 1400° F.
NR-74B-QA 2300° F water-quenched; 16 hr at 1400° F.

[b]Estimated.